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APPLICATION OF AXIOMATIC DESIGN TO ELECTRIC BICYCLES

Master's Thesis in

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ABBREVIATIONS

CA	Customer attribute
DP	Design parameter
ECCS	Emergency core cooling system
FR	Functional requirement
GPS	Global positioning system
KAIST	Korea Advanced Institute of Science and Technology
LT	Lower triangular
MRS	Market requirements specification
NPP	Nuclear power plant
OEM	Original equipment manufacturer
OLEV	On-line electric vehicle
PV	Process variable
SUV	Sports utility vehicle
UT	Upper triangular

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ABSTRACT:

Market conditions and the situation inside electric bicycle producing companies require a product development process which ensures that customer requirements are met and problems in product design are identified at an early stage. Therefore, this research takes an analytical approach towards the development of electric bicycles by applying Axiomatic Design, which offers both a holistic framework for product development as well as analytical mapping in between the individual steps of the design process. The application is done as a case study at a German electric bicycle manufacturing company and based on a collection of customer feedback as well as the contribution of the company's management. In the design process, functional requirements and design parameters are formulated and a design matrix is created to identify and resolve coupling issues. Further, constraints such as price, weight and ease of use are taken into account and process variables for practical implementation are suggested. The study results in recommendations for a specifications sheet of a new electric bicycle model. It is concluded that Axiomatic Design is of substantial advantage to the case company's product development. Future research is suggested to improve the level of detail and quality of electric bicycles designed by Axiomatic Design.

KEYWORDS: axiomatic design, electric bicycles, generic product development, quality function deployment

1. INTRODUCTION

A central issue in product design is the fulfilment of customer needs. At the same time, efficient engineering of products is important to avoid rework and reduce product life cycle cost. Both of these factors are especially true for the development of electric bicycles at Third Element GmbH & Co. KG (further referred to as 'Third Element'). First, the market for electric bicycles is rapidly growing, dynamic and diversified (ZIV 2013: 63). This makes it challenging to design products that successfully address customer needs, especially for small companies such as Third Element which do not have the resources for extensive market research. Second, it is crucial for those companies to organize their development processes in an efficient way in order to avoid rework. Recalls of electric bicycles and bankruptcies of firms in the industry have shown that the complexity of electric bicycles is often underestimated and mistakes in their design are recognized too late (myStromer: 2013).

Axiomatic Design has the potential to address both of these issues. The importance of customer needs is addressed by putting customer feedback at the very beginning of the design process and effectiveness is pursued by taking an analytical approach to transform those requirements into functions and physical properties of a product. The advantages of this methodology are better matching of product functions with customer requirements, better consistency in between functions and physical parts and, thus, more efficiency and less cost during the life-cycle of a product (Axiomatic Design Solutions 2014b).

There are numerous studies connected to electric bicycle design using other methods than Axiomatic Design. Hsu, Liu and Chan (2012) have studied power management of electric bicycles based on reinforcement learning. Xiao, Liu, Du, Wang and He (2012) have applied topology optimization to frame design of electric bicycles. Wu and Sun (2013) have designed and analysed a novel speed-changing wheel hub with an integrated motor for electric bicycles, using analytical modelling. Liang, Lin and Chang (2006) have used a fuzzy logic and single chip approach to develop an intelligent control for electric bicycles. Hua and Kao (2011) have designed a regenerative braking system for electric bicycles by experimenting with digital signal processing. Further studies apply

Axiomatic Design to the design of non-electrical bicycles, for example the case study conducted by Guo, Jiang, Zhang and Tan (2012). However, little research has been done on the combination of Axiomatic Design and electric bicycles.

In order to fill this gap and to explore how Axiomatic Design can help to deal with the issues in the field, two questions are addressed in this study: "How does an Axiomatic Design based electric bicycle look like?" as well as "What are the opportunities and limitations of Axiomatic Design with this case?" The first question marks the main goal of this study, the creation of a proposal for an electric bicycle which fulfils the needs of Third Element's customers in the best possible way. The second question aims at a brief evaluation of the approach taken, possibly helping the case company with the decision on further pursuing this matter.

The general approach of this study is that of the application of a scientific method to practical problems in a realistic and feasible way. All measures described have the potential of generating actual benefit for businesses, as shown by the specific recommendations made in the results of this research. Further the study is directed towards easy implementation in companies by suggesting changes on different levels. Incremental changes require little effort to implement and take place with the adaption of existing parts and features to improve customer satisfaction. Structural changes such as the arrangement of components take place when coupling issues are resolved. Disruptive changes alike the proposed innovative charging system are likely to take more implementation effort but bear potential for future innovation and further differentiation from competitors.

In the following, information on the background of this case and the methodology is presented. Subsequently, the data collection is described, followed by the application of the Axiomatic Design framework: The formulation of functional requirements, design parameters, process variables and constraints as well as the creation of a design matrix. Finally, the results of this process will be presented and discussed.

2. BACKGROUND AND LITERATURE REVIEW

This section provides the theoretical knowledge the research is based on. A brief description of electric bicycles, the market of those and the case company is followed by an explanation of the theory of Axiomatic Design and other product development methodologies.

2.1. Electric bicycles

Electric bicycles can be defined by the main characteristic that, in addition to the features that come with a regular bicycle, "an electric motor supplements pedal power, usually powered by a rechargeable battery" (Pucher and Buehler 2012: 81). In addition to the electric motor and the rechargeable battery, the electric powertrain also comprises an electric controller, controller software, a display with input and output functionality, as well as several sensors and switches.

The motor is often placed at the rear- or the front wheel (hub-motor) or at the pedal crank (centre-motor). Sensors may include a speed sensor which detects the movement speed of the vehicle and a torque sensor in the pedal crank which measures the human force applied to the pedals. The torque sensor allows control over the electric powertrain in a way that electrical assistance will be provided in combination with pedalling only, which is referred to as 'pedal assist mode'. In most European countries this mode of electric bicycle operation has become a standard for legal reasons. If the electric motor operates independently from pedalling, the vehicle is considered as a motorbike and additional regulations apply. (Larminie and Lowry 2012: 271-272.)

Another approach to distinguish in between electric bicycles and electric motorbikes is given by Raines, stating that there are primarily two variants of electric two-wheelers: Bicycle style electric bikes or scooter style electric bikes (Raines 2009: 69). In this context, it should be noted that it is not only the legal consequences which make a difference, but also the overall physical appearance of the vehicle, which has a strong impact on customer perception.

Figure 1. An electric bicycle by Third Element. (Third Element: 2014c)

2.2. The European electric bicycle market

The market for electric bicycles is rapidly growing. While there has been little development in production and sales of regular bicycles from 2008 to 2012, sales volumes of electric bicycles have been remarkably increasing during the same period. The increase was roughly 200 000 units per year, resulting in a total of 1.1 million units sold in 2012. (ZIV 2013: 63.)

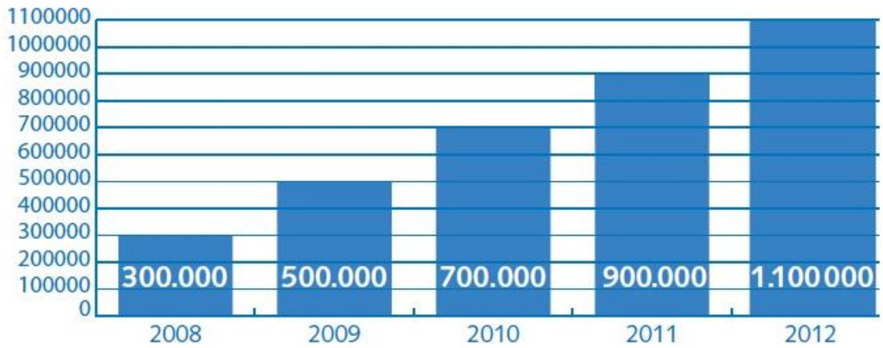

Figure 2. Electric Bicycle Sales in Europe. (ZIV 2013: 67)

At the same time, this market is dynamic. While in other industries such as machinery and automotive, the lifetime of a product usually is several years until a major model update is required, a bicycle becomes outdated just one year after its introduction to the market. In Europe the cycle time of bicycles is dominated by the Eurobike Trade Fair which takes places in Friedrichshafen, Germany in every August or September. At this trade fair, bicycle manufacturers present their model line-up for the following year and retailers make their orders. Due to the great importance of the Eurobike, many customer statements that originated from this event have been taken into consideration for this study. (Messe Friedrichshafen 2014.)

Finally, the market for electric bicycles is also diversified. Users of bicycles can be men or women of all ages and occupations, with differing health level, income, likes or dislikes. Among these users there is a broad bandwidth of requirements, reaching from senior citizens that seek recreation and health (Gojanovic, Welker, Iglesias, Daucourt and Gremion 2011), to extreme athletes who want to push their limits (McClellan 2013: 15). Large bicycle manufacturers try to address this diversification by a vast range of products. Small- and mid-sized companies like Third Element however, do not have the resources to create and maintain a line-up of dozens of models every year. Therefore it is most important to these companies to make model decisions wisely and to create a product that actually fits to the expectations of their target customers.

2.3. Case company

This research is based on the case of Third Element, an original equipment manufacturer (OEM) of electric bicycles located in Gauting, greater area of Munich, Germany. Third Element was founded in 2009 when prototypes of a newly developed electric bicycle were tested. This model combined a fullsuspension mountain bike with a powerful electrical assist, which was an innovation to the market at the time. In 2011 the company received the official listing from the Federal Office for Motor Traffic Germany as a certified manufacturer, enabling the company to series production also of such electric bicycles that require a type approval. In 2012 Third Element presented a new model line-up, adding hardtail mountain bikes and bicycles for urban use to the existing models of fullsuspension mountain bikes. With this step the company made a move to becoming a full-range bicycle manufacturer. (Third Element 2014a.)

Third Element's products are positioned in the premium segment of the electric bicycle market. The premium status is claimed by using quality components and manufacturing in Germany as well as superior appearance and technology with „the aim of giving users the possibility of moving in a modern, stylish and highly efficient way" (Third Element 2014a). With the numerous customer expectations for premium products on the one side, and the high cost for quality components and manufacturing on the other, Third Element often faces the challenge of keeping their products both attractive and profitable.

2.4. Applications of Axiomatic Design

Since its postulation by Nam P. Suh, Axiomatic Design and its principles have been applied to numerous cases. The applications comprise both physical and non-physical products as well as services. Furthermore the dimensions of products or services vary from small individual entities to large and complex systems. In the following, examples of Axiomatic Design applications in different kinds of industries will be given.

2.4.1. Application to software design

Suh and Do (2000) demonstrated that Axiomatic Design can also be applied to software. In their paper "Axiomatic Design of Software Systems" an approach to object-oriented programming of large software systems is explained. Herein a process was defined which consisted of three main steps:

- Building the software hierarchy by the recognition of customer attributes, FRs, mapping and decomposition
- Identifying of leaves depending on the software modules defined
- Building the object oriented model by identifying classes, establishing interfaces and coding with system architecture

As a result the ACCLARO software system was created, in order "to help designers to develop rational and correct designs from the beginning without resorting to prototypes and debugging" (Suh and Do 2000: 100). To the date of this research the ACCLARO software has become a versatile tool for design, comprising the key elements of

- Voice of the customer (VOC) capture
- Axiomatic Design
- Quality Function Deployment (QFD)
- Failure Mode Effects Analysis (FMEA)
- Innovation Tools (TRIZ)

and is available for purchase from Axiomatic Design Solutions via the web pages of DFSS Software. (Axiomatic Design Solutions 2014a.)

2.4.2. Application to system design

Heo and Lee (2007) have evaluated the design of emergency core cooling systems (ECCS) for nuclear power plants. In this research the ECCS of the Korean NPPs "Advanced Power Reactor 1400 MWe" (APR 1400) and "Optimized Power Reactor 1000 MWe" (OPR 1000) were compared to each other using Axiomatic Design. FRs and DPs were defined and DMs were created for the ECCS. While the design matrix of APR 1400 was uncoupled and that of OPR 1000 was decoupled on the top-level, coupling of sub-components was found in the low-level design matrices of both systems. Due to these findings, designers were able to improve the set-up of a coolant injecting device by separating flow rate and flow path. (Heo and Lee 2007.)

2.4.3. Application to product design

Suh, Cho and Rim (2010) have developed a concept for an on-line electric vehicle (OLEV) which draws electric energy from underground electric coils using induction technology. The design consisted of eight top-level FRs, eight top-level DPs and five constraints. For example, FR_7 required that electric power has to be provided to the vehicle even if there is no external power supply. Therefore, DP_7 was established which defined that the vehicle has to be equipped with a re-chargeable battery which serves as a backup if there is no underground power supply. These top-level FRs and DPs were then decomposed into lower-level FRs and DPs, further detailing the design concept. A design matrix was created which related the FR vector to the DP vector. The authors state that an integration team of the project was able to eliminate coupling and create a final design that was either uncoupled or decoupled. Subsequently two prototypes – one electric bus and one electric sports utility vehicle (SUV) – were built at Korea Advanced Institute of Science and Technology (KAIST) and tested. The concept showed to be promising and was reported to have substantial advantages towards plug-in battery electric vehicles such as lower cost of infrastructure deployment, less weight, independency from lithium resources and the ability to charge during drive. (Suh et al. 2010.)

2.4.4. Literature review of 2009

In their extensive literature review, Kulak, Cebi and Kahrman (2009) have investigated applications of Axiomatic Design from 1990 to 2009. Of the 63 papers studied, Axiomatic Design was applied to product development in 20 cases. Further fields of application were system design, manufacturing system design, software design, decision making and others. A frequency analysis of the papers published from 1990 to 2009 showed that the popularity of Axiomatic Design applications has increased since the early 2000's. The authors classified the papers also according to their focus either on the independence axiom or the information axiom. In 45 cases a focus was put on the independence axiom. The other papers either emphasized the information axiom or considered both axioms equally. (Kulak et al. 2009.)

2.5. Axiomatic Design theory

This research uses the method of Axiomatic Design. Axiomatic Design establishes a scientific basis for design. It provides logical and rational thought processes and tools which help to improve product design activities and reduces the random search process.

2.5.1. Domains and mapping in between domains

The Axiomatic Design Framework consists of four domains which describe the Customer Attributes (CAs), Functional Requirements (FRs), Design Parameters (DPs) and Process Variables (PVs) of a design task. Starting from the CAs, each further domain is reached by an analytical mapping process. (Suh 2001: 5, 11).

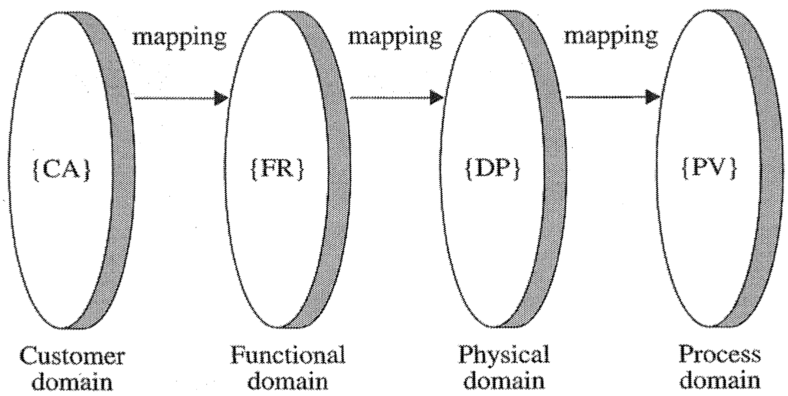

Figure 3. The four domains of Axiomatic Design. (Suh 2001: 11)

In the customer domain, the needs or attributes of customers are assessed. In the next step, these are translated into FRs of the product or service which is about to be created, asking for "what" the solution should do. Following that, answers to "how" the requirements can be satisfied in reality are sought in the physical domain. Finally, the process domain defines the production of the solution. (Suh 2001: 10.)

Mapping in between domains is an analytical process, which can be mathematically formulated using vectors and matrices. For example, the mapping in between the Functional Domain and the Physical Domain of a design that has three FRs and three DPs is described as:

$$\{FR\} = [A]\{DP\}, \tag{1}$$

where

$$[A] = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \tag{2}$$

is referred to as the design matrix which defines the interconnections in between FRs and DPs. (Suh 2001: 18.)

Design matrices can be uncoupled, decoupled and coupled. In an uncoupled design as shown in (3), [A] is a fully diagonal matrix, which means that each DP is connected to exactly one FR. This is the best possible solution because all design attributes are independent from each other.

$$[A] = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \tag{3}$$

In a decoupled design (4), [A] is a triangular matrix, which leads to dependencies in between design attributes to a limited extend. Both lower triangular (LT) and upper triangular (UT) matrices are possible (Suh 2001: 19). This design is not ideal, but acceptable if no other options exist.

$$[A] = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & 0 & X \end{bmatrix} \tag{4}$$

A coupled design (5) has dependencies above and below the diagonal. Changes in one design attribute are likely to affect many other design attributes as well. This leads to high levels of dependency and has to be avoided.

$$[A] = \begin{bmatrix} X & 0 & X \\ X & X & 0 \\ X & 0 & X \end{bmatrix} \quad (5)$$

In the next step, the mapping from the physical domain to the process domain can be described as

$$\{DP\} = [B]\{PV\}, \quad (6)$$

where [B] is a matrix similar in form to [A] and describes the process design for the transition of DPs into PVs (Suh 2001: 409).

PVs refer to all measures that can produce DPs. For example with materials production and processing, PVs can describe manufacturing processes required to achieve the design goals specified. With organizations and businesses, PVs may refer to human and financial resources. (Suh 2001: 12.)

2.5.2. Decomposition, hierarchy and zigzagging

FRs, DPs or PVs are arranged in a hierarchy, consisting of higher and lower level elements. The process of building those hierarchies is called decomposition, starting from a top-level element and going more and more into details. However, decomposing is not done sequentially domain by domain, but by zigzagging. Zigzagging (as indicated by the dashed arrows in **Figure 4**) means to go forth and back in between domains during the decomposition process. For example if FR_1 is defined, DP_1 is defined after that. Next, FR_1 is decomposed into FR_{11} and FR_{12} and immediately after that their equivalents in the physical domain are sought. This method seeks to avoid divisional thinking, which often happens with organizations where for example the design specification is solely carried out by one department and the design realization is done by another department. (Suh 2001: 29-31.)

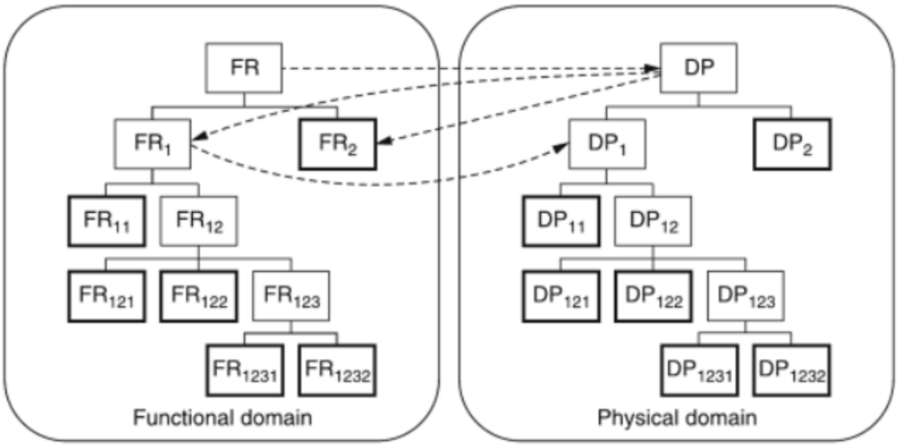

Figure 4. Decomposition of FRs and DPs. (Suh 2001: 30)

2.5.3. Axioms

There are two main principles which the Axiomatic Design approach is based on. These are formulated as follows:

- The Independence Axiom: "Maintain the independence of the functional requirements (FRs)."

- The Information Axiom: "Minimize the information content of the design."

(Suh 2001: 16.)

The independence axiom states that a design has to be done in a way that the FRs of that design can be fulfilled without affecting each other. This means in turn that the DPs which shall satisfy the FRs have to be chosen wisely. Otherwise the independence of FRs may not be maintained. (Suh 2005: 23.)

Considering the three types of design matrices explained in the previous section, an uncoupled design would fully satisfy the independence axiom. With decoupled designs, FRs are not fully independent but since it is difficult to avoid all kinds of dependencies especially with difficult designs, this can still be considered acceptable. With coupled designs however, the interdependencies have reached an extent that the independence axiom has to be considered as violated.

The Information Axiom helps to find the best design solution among different possibilities. There may be several designs which all fulfil the Independence Axiom, however, some of those may be superior to others. According to the Information Axiom, the best design among those possibilities is the one that has the smallest information content I_i. The smaller the information content, the less information is needed to reach the design goals. The information content can be computed by calculating the probability P_i of satisfying FR_i, also known as the probability of success. While there are many ways to do this, one possible solution is

$$I_i = \log_2 \frac{1}{P_i}. \tag{7}$$

(Suh 2005: 30.)

The probability of success can be calculated by taking a closer look on the design range and the system range of a FR. The design range is the area which comprises all values that are acceptable to satisfy a FR. The system range contains all values that the proposed design can have. The common range equals to the overlap of design range and system range. For example in the case of cutting a rod to a certain length, the tolerance specified to the desired length refers to the design range while the machine which is chosen to cut the rod corresponds to the system and the tolerance of that machine is the system range.

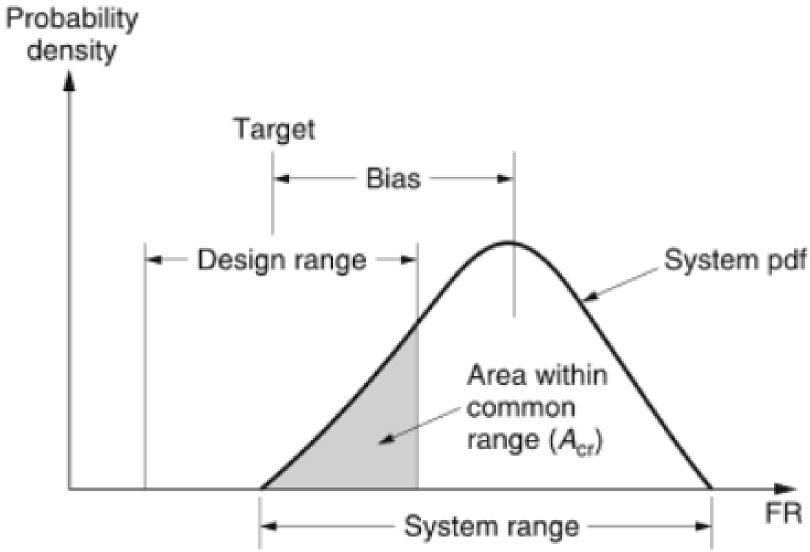

Figure 5. Design range, system range, common range and system pdf. (Suh 2005: 32)

Information content and probability of success ultimately lead to the subject of complexity. Suh defines that "a design is called complex when its probability of success is low, that is, when the information content required to satisfy the FRs is high"(2005: 31). With a complex task, the design range is small and the system range is large, so there is little overlap in between both ranges and thus the probability of success is small. In contrast, with a simple task the design range is large and the system range is small, so that there is much overlap and the probability of success is high. Therefore, it should be the designer's goal to keep requirements as simple as possible and choose methods that have high capability of meeting requirements. In other words, simple solutions should be chosen in favour of difficult ones and the level of precision should be held within reasonable limits.

2.5.4. Corollaries

Further eight corollaries exist. Following these rules helps to satisfy the two axioms and find the best possible design solution. The corollaries are:

1. Decoupling of coupled designs: Separate parts or aspects of a solution if FRs are interdependent in a proposed design.

2. Minimization of FRs: Use as little FRs and constraints as possible.

3. Integration of physical parts: Combine design features in a single physical part if FRs can be independently satisfied in that solution.

4. Use of standardization: Use standardized of interchangeable parts if possible regarding the FRs and constraints.

5. Use of symmetry: If possible in terms of FRs and constraints, use symmetrical shapes and/or components.

6. Largest design ranges: When stating FRs, use the largest allowable design range.

7. Uncoupled design with less information: Seek uncoupled designs with less information in favour of coupled designs.

8. Effective reangularity of a scalar: For a scalar coupling matrix or element, the effective reangularity is unity. Reangularity is a metric for the degree of coupling in between design elements.

(Suh 2001: 60.)

2.5.5. Theorems

Further there are theorems related to different subjects in design. Theorems provide background and proof for the corollaries stated above. 26 theorems exist on general design, nine theorems relate to design and decomposition of large systems, three theorems deal with the design and operation of large organizations and two further theorems describe software design. (Suh 2001: 61-64.)

Theorem 1, 3 and 4 define the three basic types of design: Coupled, redundant and ideal design.

- Theorem 1: Coupling due to insufficient number of DPs

  If there are more FRs than DPs, the design will either be coupled or FRs cannot be satisfied. The independence axiom will be violated in any case. For example in a design with three FRs and two DPs the design equation is

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \\ A_{31} & A_{32} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}, \tag{8}$$

  where A_{31} and A_{32} being 0 would mean that FR_3 is not satisfied and being non-zero would result in a coupled design.

- Theorem 3: Redundant design

  If there are more DPs than FRs, the design is called redundant. While some redundant designs violate the independence axiom, others do not. For example a design with two FRs and five DPs has the equation

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \end{Bmatrix}, \tag{9}$$

  where, depending on the values of A_{11} to A_{25}, the design is either coupled or redundant.

- Theorem 4: Ideal Design

  If the FRs and DPs of a design are equal in number and the independence axiom is satisfied, the design is called an ideal design. For example (2) represents the design matrix of an ideal design, assuming that A_{11} to A_{33} are chosen in a way that the independence axiom is not violated.

(Suh 2001: 22-24.)

2.5.6. Example of a coupling problem

A prominent example of a coupling problem and its solution is the design of a refrigerator door. In this case, it is assumed that two FRs exist which can be formulated as follows:

FR_1: Provide access to the items inside
FR_2: Minimize energy loss

The solutions as in **Figure 6** a) satisfies these FRs with the DPs

DP_1: Vertically hung door
DP_2: Thermal insulation material

This leads to a design equation which can be stated as:

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}, \qquad (10)$$

This is a decoupled design. The door provides access to items and the insulation material has a positive effect on energy consumption. However, the vertically hung doors also have an effect on FR_2 – a negative one – since cold air will flow out of the refrigerator once a door is opened.

With the solution as in **Figure 6** b), the DPs are:

DP_1: Horizontally hung doors
DP_2: Thermal insulation material

which results in the design equation

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}. \qquad (11)$$

This concept is similar to solution a) with the difference that the doors attachment method does not have an influence on thermal insulation. Since cold air is heavier than hot air, it will stay inside the refrigerator if the doors are mounted on top of it. The result is an uncoupled design which is superior to the decoupled design of solution a). (Park 2007: 20-22.)

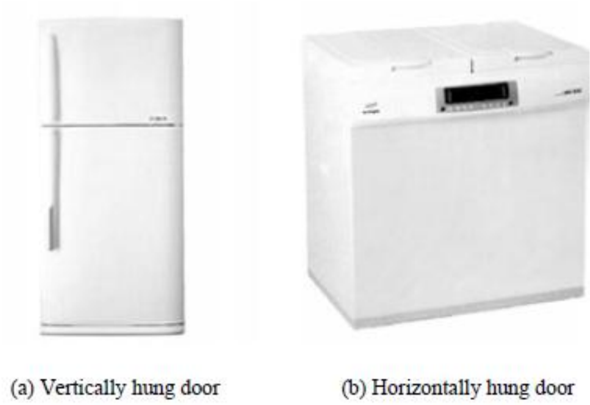

Figure 6. Refrigerator door design. (Park 2007: 21)

2.5.7. Limitations of creating FRs based on customer feedback

Customer feedback does not necessarily create CAs and FRs. Suh mentions that input given by customers is important, however there may be problems in determining FRs solely based on this type of feedback. First, preferences of individuals may not correspond with the preferences of a group as a whole. Second, a listwise collection of customer statements – often referred to as marketing requirements specification (MRS) – usually is a random mixture of CAs, FRs, DPs, PVs and constraints from the point of view of Axiomatic Design. This leads to numerous constraints and little freedom which makes design very complicated. Third, when translating CAs to FRs, the range of usage must be specified. However, users seldom specify such a range. (Suh 2001: 14-15.)

Due to these reasons, the mapping process from CAs to FRs is not of the analytical kind as with the other domains and designers are asked to come up with their own ideas of defining FRs in the best possible way. This freedom of choice of FRs leaves room for criticism. For example Mann (2002: 4) pointed out that – despite the arguments put forth by users of Axiomatic Design – a large number of freezers with vertically hinged doors had been sold, concluding that the FRs chosen for that design could not be the requirements most important to customers.

2.6. Other design methodologies

Besides Axiomatic Design, a number of product development and design methods exist in practice. In the following, two other prominent principles will be explained briefly: The Generic Product Development process by Ulrich and Eppinger and Quality Function Deployment (QFD). Generic Product Development is presented because it has an approach different from Axiomatic Design by employing a sequential process flow through organizational entities. QFD however is a tool that shares certain elements with Axiomatic Design and in addition to that, there has been research on applying both theories together, such as the study by Carnevalli, Miguel and Carnage (2010).

2.6.1. Generic Product Development

Ulrich and Eppinger describe product development as a process that follows a structured flow, a "sequence of steps or activities that an enterprise employs to conceive, design, and commercialize a product" (Ulrich and Eppinger 2012: 12). The process is generic and has six phases, as depicted in **Figure 7**, starting from the planning phase and ending with the production ramp-up. In between these steps there are reviews or gates which correspond to the completion of the phase.

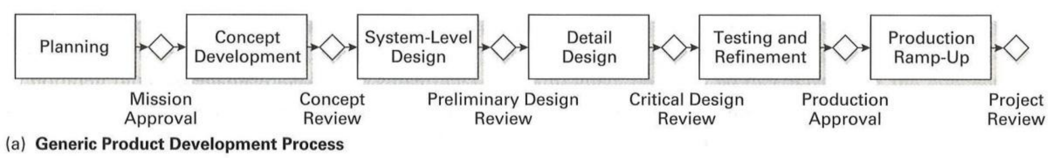

Figure 7. Generic Product Development Process. (Ulrich and Eppinger 2012: 22)

Depending on the type of product that is about to be designed, the development process may differ. While the Generic Product Development process is suitable for market-pull, technology-push, platform, process-intensive, customized, and high-risk products; the spiral process is considered to be a good fit for quick-built products. This process has iteration cycles in the detail design and testing phase, which create better flexibility and responsiveness during the development of a product. For complex systems such as automobiles and airplanes, a development process is proposed which has parallel design- and test phases for sub-systems and components, followed by phases of integration and testing of the whole system. This is especially suitable when product development is done by many teams at once. (Ulrich and Eppinger 2012: 22.)

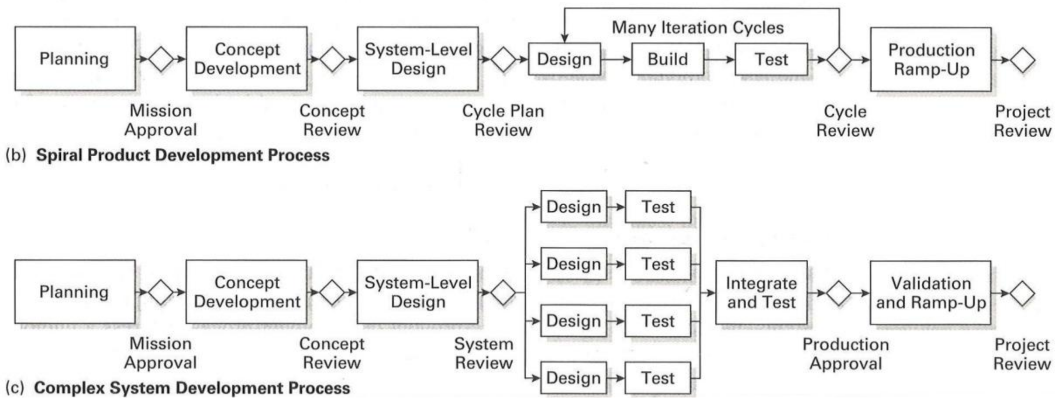

Figure 8. Spiral and Complex Development Processes. (Ulrich and Eppinger 2012: 22)

Ulrich and Eppinger present a sequential approach towards product development. The emphasis lies on organizational and managerial aspects, which will guide companies and designers along their path towards the completion of a new product. Risk-management, quality and improvement aspects are also included. For example, the reviews in between phases may help to recognize problems and avoid misleading developments. With the complex system development process, Ulrich and Eppinger also investigate the aspect of decomposition of systems and give advice how to deal with sub-systems and components. Other than Axiomatic Design, which tries to avoid divisional thinking by zigzagging in between domains, Generic Product Development follows a series of sequential steps division by division.

2.6.2. Quality Function Deployment

Quality Function Deployment (QFD) is “a method for structured product planning and development”(Cohen 1995: 11) that follows a process to correlate customer requirements with product properties and the technical specification of the product using a morphological chart.

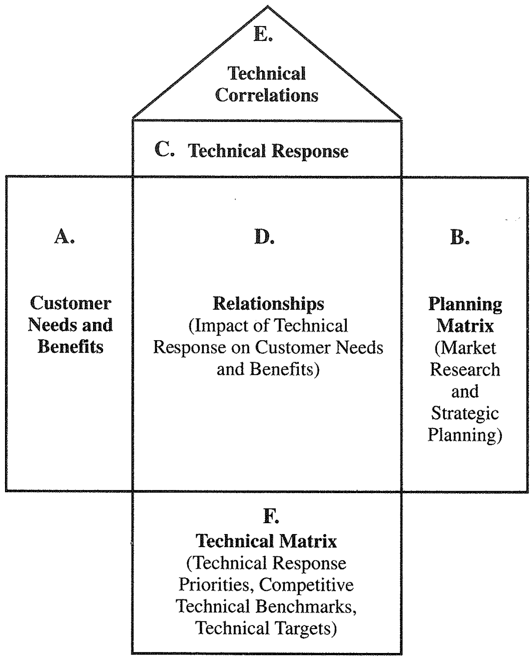

Figure 9. The House of Quality. (Cohen 1995: 12)

The central structure of QFD is the House of Quality, which consists of a customer needs as well as a technical response section, a relationships matrix (also referred to as correlations matrix), a section for correlations in between technical responses, a planning matrix and a technical matrix (Cohen 1995: 11). The correlation in between customer requirements and product properties is done in the relationships matrix. First, each customer requirement is given a weight depending on how important the requirement is to the customer and each product property is given a value according to the importance of that property towards the customer requirement. Subsequently, all property values are multiplied with the requirements weight to create relative weights. The result is a ranking of product properties according to their importance to fulfil customer requirements. Finally, for each product property exactly one design element can be defined, whereas dependencies in between elements may apply. Properties may be specific (e.g. "optical link") or specific (e.g. "flat screen display"). The list of all design elements leads to the specification sheet of the product.

There are advantages and disadvantages with the use of QFD. Benefits of QFD were found to be less project changes, reduction in project time, increased revenue, reduced complaints and increased customer satisfaction while difficulties in working with large matrices, interpretation of the customer voice and identifying the importance of customer demands were found to be frequent problems of the method (Carnevalli and Miguel 2008: 742).

3. METHOD

This research was carried out as a single company case study for Third Element in Munich, Germany. The proceeding was divided into four steps: First, a data collection on customer feedback was conducted within the case company in order to assess the needs of their customers. Second, a preliminary design was made and presented to the General Manager of Third Element. Third, a mid-term review was held, in which the General Manager added his comments and suggestions to the preliminary design. Last, the author improved and finalized the design.

3.1. Data collection

The Axiomatic Design process starts with the customer domain which assesses the needs of customers. In order to familiarize with the needs of Third Element's customers, an extensive data collection was conducted within the company. All data used in this research is secondary data from organisational records of Third Element. The records comprise notes from trade fairs and exhibitions, test drive evaluations, emails from retailers and users, internal evaluations and a survey among retailers conducted by a consultant agency. The oldest document taken into account was an employee's note from May 2010 and the newest was a test drive evaluation from November 2013.

Based on this material, a total of 440 customer statements were identified. The individuals that gave feedback were categorized into three types: "Consumer" refers to private people that use electric bicycles or have an interest in those. "Business" customers are mostly bicycle retailers. "Internal" means that the feedback was either given by an employee of Third Element or the result of an in-house evaluation. The majority of 161 customer statements originated from consumers, followed by 142 statements of business customers. 65 statements came from inside the company. With 72 statements it was not possible to identify from whom they originally came from and therefore the feedback provider was marked as "unknown".

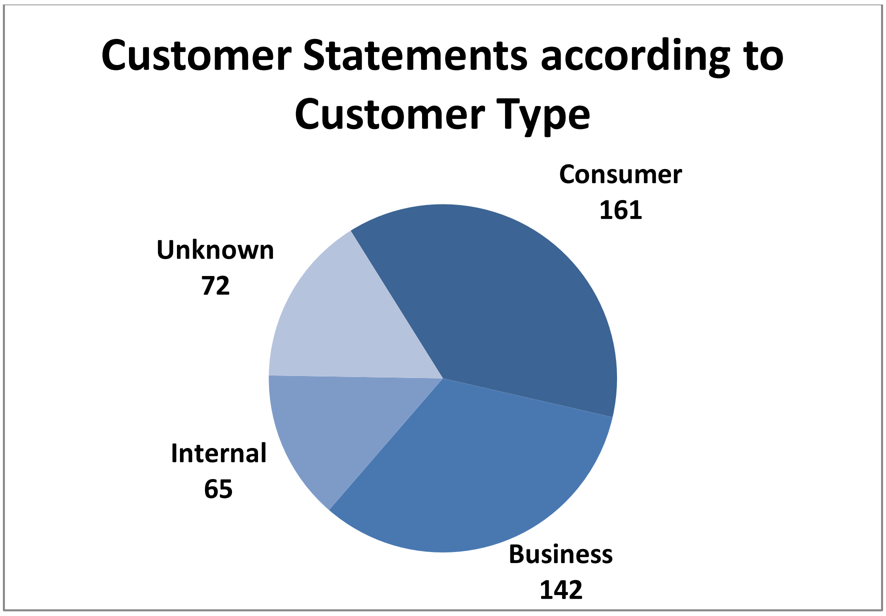

Figure 10. Customer statements according to customer type.

Sorting and processing of the data was done manually. Due to the number of customer statements, redundancy, and varying impact on decision making, a 'sort and combine' approach was taken. This means that statements to the same topic were sought and if suitable, condensed into a FR or DP as illustrated by the example given in **Figure 11**.

Id.	**Customer statement**
49	"Quite a lot of force needs to be applied to the brake levers to generate an acceptable deceleration."
62	"The brakes were still sufficient, although you could feel that they were stressed."
217	"Insufficient brakes."

FR_7: Have sufficient brake force

A brake system that is capable of providing sufficient brake power, giving the user a feeling of control and safety.

Figure 11. Combination of multiple customer statements into one FR.

3.2. Design

Based on the 440 customer statements collected and the expertise of the General Manager, FRs and DPs were formulated. The identifiers (“Id.”) refer to entries in the list of customer statements which can be found in Appendix I. The structure of the modules follows the company’s modular framework for electric bicycles (Third Element: 2012b).

3.2.1. Top-level FRs and DPs

Table 1. Top-level parameters for electric bicycle design.

Index	FR	DP
1	Provide basic structure	Frame assembly
2	Allow movement	Wheelset
3	Drive electrically	Electric drive assembly
4	Drive mechanically	Mechanical drive assembly
5	Interact with user	Human interaction components
6	Have optional functions	Flexible accessories packages
7	Have sufficient brake force	Quality hydraulic disc brakes
8	Have lighting	Lighting package, frame mount

The design equation is given by

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \\ FR_5 \\ FR_6 \\ FR_7 \\ FR_8 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ X & X & 0 & 0 & 0 & 0 & 0 & 0 \\ X & X & X & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X & X & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & X & 0 & 0 & 0 \\ X & 0 & 0 & 0 & 0 & X & 0 & 0 \\ X & 0 & X & 0 & 0 & 0 & X & 0 \\ X & 0 & 0 & 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \\ DP_5 \\ DP_6 \\ DP_7 \\ DP_8 \end{Bmatrix}. \tag{12}$$

Explanations:

- FR_1 / DP_1 to FR_6 / DP_6: These top-level FRs and DPs have to be further decomposed in the following steps.

- FR_7 / DP_7: Having strong brake force was repeatedly mentioned and considered to be important, especially in connection with heavier models (Appendix 1: Id. 49, 62, 217). This calls for a brake system that is capable of providing sufficient brake power, giving the user a feeling of control and safety. Hydraulic disc brakes supply better braking performance than mechanical disc or rim brakes. However, also among hydraulic disc brakes there are significant differences in performance. Therefore, only good quality hydraulic disc brakes should be used.

- FR_8 / DP_8: Lighting refers to all components needed for use during darkness and on public roads such as front light, rear light and reflectors. This may either be required by customers' wish or by legal norms. Mounting to the frame keeps the light package independent from the mudguards and the carrier.

3.2.2. Decomposition of FR_1 and DP_1

Table 2. Decomposed parameters for frame design.

Index	FR	DP
11	High stiffness	Rigid aluminium construction
12	Good-looking weld seams	Quality welding supplier
13	Frame shock absorption	Suspension front fork
14	Unique design	Double top-tube
15	Easy to clean	Wet paint

The design equation is given by

$$\begin{Bmatrix} FR_{11} \\ FR_{12} \\ FR_{13} \\ FR_{14} \\ FR_{15} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_{11} \\ DP_{12} \\ DP_{13} \\ DP_{14} \\ DP_{15} \end{Bmatrix}. \qquad (13)$$

Explanations:

- FR_{11} / DP_{11}: Previous models had been criticized for low rigidity of the rear end and little ground clearance (Appendix 1: Id. 125, 126, 129). Although these complaints were already taken into concern with the development of newer models, the issue remains important and is thus articulated as an FR. The proposed solution is an aluminium construction that does not bend even under high loads.

- FR_{12} / DP_{12}: Frames of current models seem to have room for improvement in terms of weld seam quality (Appendix 1: Id. 70, 316). This may be addressed by choosing welding services providers with higher quality standards than previous suppliers.

- FR_{13} / DP_{13}: Latest models received criticism due to little comfort caused by the front fork (Appendix 1: Id. 50). Therefore, it is proposed to use a front fork that allows reasonable amount of travel while not yet reaching into high-level segments designed for heavy mountain biking purposes. Even entry-level forks, such as the 30 Gold TK by SRAM, offer good quality at a reasonable price (SRAM 2014).

- FR_{14} / DP_{14}: Existing models have received generally positive reviews for their exterior design and overall appearance (Appendix 1: Id. 41, 108, 176, 189). According to an internal analysis, it is mainly due to the unique frame geometry that Third Element can differentiate to competitors (Appendix 1: Id. 254), while the most significant element of this geometry is the design feature of having two parallel top tubes instead of one single tube (Third Element 2014d).

- FR_{15} / DP_{15}: The matt paint of newer generation frames was questioned in terms of dust-sensitivity and ease to clean (Appendix 1: Id. 67). In contrast, a wet-paint has a glossy surface which is not sensitive to dust and does not require much effort to clean.

3.2.3. Decomposition of FR_2 and DP_2

Table 3. Decomposed parameters for wheels design.

Index	FR	DP
21	High tyre shock absorption	Large diameter tyres
22	Low rolling resistance	Low friction profile

The design equation is given by

$$\begin{Bmatrix} FR_{21} \\ FR_{22} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{21} \\ DP_{22} \end{Bmatrix}. \quad (14)$$

Explanations:

- FR_{21} / DP_{21}: Also referring to complaints about riding comfort (Appendix 1: Id. 50, 200), the tyres were taken into concern as well. Since the diameter of a tyre defines its comfort, large diameter tyres have better shock absorbing qualities than small diameter tyres. For example, the Schwalbe Big Apple is a tyre specifically designed for comfort (Ralf Bohle 2014).

- FR_{22} / DP_{22}: Concerning electric driving range and top speed, the rolling resistance of tyres plays a viable role. An efficient road profile rolls easier than a rough mountain bike profile.

3.2.4. Decomposition of FR_3 and DP_3

Table 4. Decomposed parameters for electrical drive design.

Index	FR	DP
31	Propulsion	Motor-/gearbox unit with integrated controller
32	Interaction with electrical drive	High value display
33	Speed metering	Speed sensor, spoke magnet based method
34	Innovative charging	Inductive charging system
35	Control of the electric drive	Controller software
36	Assist during walking	Walking assist
37	Good gearshift performance	Gear sensor
38	Sufficient range	Lithium-ion battery

The design equation is given by

$$\begin{Bmatrix} FR_{31} \\ FR_{32} \\ FR_{33} \\ FR_{34} \\ FR_{35} \\ FR_{36} \\ FR_{37} \\ FR_{38} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & X & 0 & 0 & 0 & 0 \\ 0 & 0 & X & 0 & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & X & X & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & X & 0 \\ X & X & 0 & 0 & X & X & 0 & X \end{bmatrix} \begin{Bmatrix} DP_{31} \\ DP_{32} \\ DP_{33} \\ DP_{34} \\ DP_{35} \\ DP_{36} \\ DP_{37} \\ DP_{38} \end{Bmatrix}. \qquad (15)$$

Explanations:

- FR_{31} / DP_{31}: An electric motor, mechanical transmission and control unit integrated into the same housing. Using an integrated controller is consistent with Axiomatic Design because additional parts are eliminated.

- FR_{32} / DP_{32}: The display types of previous models were criticized for little functionality, low contrast and overall limited quality compared to the price of the vehicle (Appendix 1: Id. 51, 68, 85, 153). In general, monochromatic, small sized and little functionality displays indicate low value while colour, large size and high functionality indicate high value. Since the display is the main interface in between the machine and the user, it has to be appealing. Being aware of these issues Third Element has introduced the new "AF-Type" display with their latest models which offers additional features, such as a graphical interface, USB charging connector, pulse detection and cadence (Appendix 1: 268).

- FR_{33} / DP_{33}: Speed metering provides important data for other functions. Besides that, this function is required due to legal reasons (The European Parliament and the Council of the European Union 2002). While there are differing technical solutions, in this design the use of a sensor is proposed which measures the spin of a wheel by magnetic force. This decision is discussed in detail in 3.3.

- FR_{34} / DP_{34}: Charging the battery has to function without problems such as charging errors (Appendix 1: Id. 419). In addition to that, there seems to be a demand for a greater variety of charging methods, such as fast charging and plugless charging (Appendix 1: Id. 421, 422). As one of the main characteristics of this design, the use of an inductive charging system is proposed. This solution has the advantages to be reliable, easy to use and can be considered as innovative. In 2012, a concept for an electric bicycle application of this technology was developed by the German automation company SEW (SEW-EURODRIVE 2012).

- FR_{35} / DP_{35}: The controller software controls all electrical functions of the electric drive.

- FR_{36} / DP_{36}: A function to use part of the electric drive power to assist the user while moving the vehicle by hand, for example on a steep hill.

- FR_{37} / DP_{37}: Customers repeatedly reported to have difficulty with shifting gears while the drive is delivering power (Appendix 1: Id. 48, 193, 196, 199, 332). To avoid these difficulties, it is proposed to use a sensor which links the gearshift of the mechanical drive to the electric drive. This allows automatic coordination of gearshift and power supply, which results in better performance of the electric bicycle. At the time of this study, gear sensors were still under development. A prototype was built by the Czech company Agentura repro (2014).

- FR_{38} / DP_{38}: Operating range was generally considered too low, especially under heavy-load operations such as mountain biking (Appendix 1: Id. 59, 65, 150, 152, 354, 361). In addition to that, retailers stated in an interview conducted in April 2011 that battery capacity would be the most important feature of an electric drive (no. 407). At the time of this study, lithium-ion batteries were the only solution capable of addressing these high expectations.

FR_{32} and DP_{32} may be further decomposed as:

Table 5. Third level display design.

Index	FR	DP
321	Good usability	Graphical user interface (GUI)
322	High contrast	High contrast screen
323	Sufficient functionality	3 drive modes

The design equation is given by

$$\begin{Bmatrix} FR_{321} \\ FR_{322} \\ FR_{323} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_{321} \\ DP_{322} \\ DP_{323} \end{Bmatrix}. \qquad (16)$$

Explanations:

- FR_{321} / DP_{321}: GUIs have become standard for premium electric bicycles and should therefore not to be missed in this design proposal.

- FR_{322} / DP_{322}: Customers gave negative feedback on the visibility of information, asking for displays with high contrast (Appendix 1: Id. 51).

- FR_{323} / DP_{323}: 'Sufficient' means that the display functionality should serve customers' needs while not being complicated and overloaded (Appendix 1: Id. 271, 423). Customers suggested that three operating modes would be more sufficient than ten, and that the modes should have names alike "max Range", "eco" and "performance" rather than numbers (Appendix 1: Id. 325, 357, 372).

FR_{36} and DP_{36} may be further decomposed as:

Table 6. Third level walking assist design.

Index	FR	DP
361	Software function	5 km/h limiter software module
362	User interface	On/off button

The design equation is given by

$$\begin{Bmatrix} FR_{361} \\ FR_{362} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{361} \\ DP_{362} \end{Bmatrix}. \quad (17)$$

Explanations:

- FR_{361} / DP_{361}: Adds the walking assist function to the controller software. If the walking assist was not limited to a maximum of 5 km/h, the vehicle would become subject to the regulations of 2002/24/EC, which has to be avoided if possible (The European Parliament and the Council of the European Union 2002).

- FR_{362} / DP_{362}: Enables the user a control of the function. To be realised separately or integrated into the display. Following Axiomatic Design principles, the proposed design shows the separate solution causing less dependency than the integrated solution.

3.2.5. Decomposition of FR_4 and DP_4

Table 7. Decomposed parameters for mechanical drive design.

Index	FR	DP
41	Gearshift	Derailleur gears
42	Compatibility with electric drive	Single speed crankset

The design equation is given by

$$\begin{Bmatrix} FR_{41} \\ FR_{42} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{41} \\ DP_{42} \end{Bmatrix}. \tag{18}$$

Explanations:

- FR_{41} / DP_{41}: Derailleur gears have the advantage of being less expensive than other types of gears but the disadvantage that they usually do not function properly when used in electric bicycles. However, this design compensates the negative effect of derailleur gears by using a gear sensor (DP_{37}).

- FR_{42} / DP_{42}: A single speed crankset is required because motor-/gearbox units are not compatible with double or triple speed cranksets.

3.2.6. Decomposition of FR_5 and DP_5

Table 8. Decomposed parameters for human interface design.

Index	FR	DP
51	Saddle shock absorption	Comfortable saddle
52	Steering control	Quality grips

The design equation is given by

$$\begin{Bmatrix} FR_{51} \\ FR_{52} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP_{51} \\ DP_{52} \end{Bmatrix}. \quad (19)$$

Explanations:

- FR_{51} / DP_{51}: Latest models received criticism for lack of comfort due to hard saddles (Appendix 1: Id. 200). It is suggested to use a saddle that provides at least a basic level of comfort, while not being clumsy. For example, Selle Italia's X1 saddles offer a compromise in between comfort and sportiness for an entry-level price (Selle Italia: 2014).

- FR_{52} / DP_{52}: Customers of latest models asked for handlebars with good quality grips (Appendix 1: Id. 227). Therefore more attention has to be paid to the quality of grips for future models.

3.2.7. Decomposition of FR_6 and DP_6

Table 9. Decomposed parameters for accessories design.

Index	FR	DP
61	Protection from dirt	Quality mudguards without reflector mount
62	Protection from oil and grease	Quality chain protection
63	Goods transport capability	Carrier without light mount
64	Multi-media functions	Mobile phone interface

The design equation is given by

$$\begin{Bmatrix} FR_{61} \\ FR_{62} \\ FR_{63} \\ FR_{64} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_{61} \\ DP_{62} \\ DP_{63} \\ DP_{64} \end{Bmatrix}. \quad (20)$$

Explanations:

- FR_{61} / DP_{61}: Some of Third Element's bicycles are equipped with mudguards. These parts have been repeatedly criticized to create vibration, friction or dangling noises during operation (Appendix 1: Id. 251, 327, 328). Due to this criticism, it is important that accessory parts are of good quality. In addition to that, the mudguards should come without a reflector mount, which makes them independent from the lighting package.

- FR_{62} / DP_{62}: A chain protection is a plastic cover that protects the user from oil and grease of the chain. This part can increase customer satisfaction with relatively little effort and should therefore be available as an option (Appendix 1: 376).

- FR_{63} / DP_{63}: Without a light mount, the carrier is independent from the lighting package.

- FR_{64} / DP_{64}: A great variety of wishes exist which relate to mobile phone and GPS interfaces as well as more multi-media related functions in general (Appendix 1: Id. 354, 358, 363, 374, 426). To satisfy these requests, the General Manager (2014a) named the Bluetooth Low Energy Standard as a suitable technology. Examples of electric bicycles with Bluetooth functionalities can be found with the Neo models by BH Easy Motion (Electric Cyclery 2014).

3.2.8. Constraints

Table 10. Constraints table.

Index	Constraint	Impacts FR							
		1	2	3	4	5	6	7	8
1	Cost	-	-	-	-	-	-	-	-
2	Weight	-	-	-	-	-	-	-	-
3	Creates fun	-	-		-	-	-		
4	Easy to use	-	-	-	-	-	-	-	-
5	Legal requirements	-	-	-	-			-	-

Description of Constraints:

- C_1: Price was generally considered too high, or at least at the upper price level of the respective vehicle type (Appendix 1: Id. 32, 148, 391). Therefore, material and labour cost have to be monitored carefully. Suh (2001: 21) suggests treating costs as a constraint rather than a FR, because costs are affected by all design decisions and, thus, cannot be independent from other FRs.

- C_2: Weight was generally considered too high across all products and customer types (Appendix 1: Id. 127, 128, 204, 206, 213, 215). One business customer even demanded for “less weight and greater driving range at the same time” (Appendix 1: Id. 430).

- C_3: There is a large amount of statements on the subjective perception of users when operating Third Element electric bicycles. Customers would like to have good support from the electric drive in every operating situation, such as uphill, downhill or on flat land (Appendix 1: Id. 24, 169, 171). Concerning the question on how “good support” can be defined in more detail, there is a great variety of possible answers. While some appreciate high electric power in particular (Appendix 1: Id. 98, 143, 177), others describe their positive riding experiences independent from the rated output of their bicycles, for example “smooth” or “agile” behaviour (Appendix 1: Id. 83, 166). Independent from the specific model used, customers seek for "fun" (Appendix 1: Id. 136, 188, 382, 396).

- C4: In the same manner as with C_3, there is a large number of statements on the factor how difficult it is to operate the electric bicycle, wishing for easy solutions (Appendix 1: Id. 175, 179, 183, 188, 190, 310). While this is not astonishing, the realization of this wish is complex, because ease of use depends on a great variety of functions in different use cases. By suggesting this constraint, an underlying element is created to all design decisions that affect ease of use.

- C_5: Customer feedback on legal requirements is contradicting. Customers appreciate to have little legal requirements and oppose the idea of having to have insurance or wearing a helmet (Appendix 1: Id. 394 403, 404). However, there is a number of customers that dislike the electrical assist to be limited to a top speed of 25km/h (no. 87, 88) and some even oppose the limit of 45km/h as well (Appendix 1: Id. 29, 30). At the same time, customers that have a bicycle with 45km/h limitation, ask for a "pedelec function" to switch in between faster and slower operation modes (Appendix 1: Id. 117, 124, 131). If the assist is not limited to a maximum of 25km/h, the vehicle should have an approval and has to be equipped with all components required for operation on public roads, such as a license plate holder (Appendix 1: Id. 23, 235, 367).

3.2.9. Design matrix

Mapping in between the functional domain and the physical domain was done according to formula (1), resulting in the design matrix shown in **Figure 12**. The layout of the design matrix used in this research is a combination of the matrices used by Carnevalli et al. (2010: 6) as well as Suh (2001: 282-283). The FRs, as formulated in the previous sections, can be found in rows while the DPs are shown in columns. An "X" at the intersection of a FR and a DP indicates dependence in between both elements, while an empty cell means that there is no dependence. Cells on the diagonal are highlighted in grey, making it easier to see that the result is a LT matrix which corresponds to a decoupled design as described in (4). Thus, the design is not coupled but there are interdependencies. For example, FR_{21} (high tyre shock absorption) is not only affected by DP_{21} (large diameter tyres) but also by DP_{11} (rigid frame construction) and DP_{13} (suspension front fork), because frame and fork dimension have to fit together with tyre dimensions.

FRs			DPs																											
			1					2		3											4		5		6				7	8
			1	2	3	4	5	1	2	1	2	2	2	3	4	5	6	6	7	8	1	2	1	2	1	2	3	4		
											1	2	3				1	2												
1	1		x																											
1	2			x																										
1	3				x																									
1	4					x																								
1	5						x																							
2	1		x		x			x																						
2	2								x																					
3	1		x							x																				
3	2	1									x																			
3	2	2									x	x																		
3	2	3											x																	
3	3													x																
3	4		x												x															
3	5													x		x														
3	6	1												x		x	x													
3	6	2												x		x		x												
3	7																		x											
3	8		x						x	x	x		x			x				x										
4	1									x									x		x									
4	2									x												x								
5	1							x															x							
5	2																							x						
6	1		x		x																				x					
6	2																									x				
6	3																										x			
6	4																											x		
7			x		x					x																			x	
8					x																									x

Figure 12. Design Matrix.

3.2.10. Suggestions for PVs

- PVs for DP_{12} (quality welding supplier) may comprise values related to the welding process such as welding method, type of filler material and degrees of freedom during the welding process (Weman 2012 :210).

- DP_{14} (wet-paint) may be further defined by variables relevant to the tasks done in the paint shop, for example the number of layers applied.

- DP_{21} (large diameter tyres) and DP_{22} (low friction profile) may result either from automated or manual ('hand-made') tyre manufacturing processes.

- Since DP_6 (flexible accessory packages) and all of its sub-components are optional parts, it is advisable to define inventory control parameters for the manufacturing process, such as safety stock to meet fluctuations in demand (Hopp and Spearman 2011: 73).

- With DP_7 (quality hydraulic disc brakes) it can be relevant to choose either manufacturing in Germany or manufacturing in other parts of the world.

3.2.11. Example of calculating the information content

With FR_{13} (suspension front fork) the requirement for a "reasonable amount of travel" (cf. 3.2.2) was discussed. With this wording, it should be questioned what is 'reasonable' and how can the requirement be quantified? The solution can be found in the calculation of the information content.

Assumed that the majority of customers considers a travel of up to 100 mm as reasonable, the system range for this FR is 0-100 mm. Further it is assumed that Third Element wanted to investigate two design options: Fork 1 with 80 mm maximum travel and fork 2 with 100 mm maximum travel.

In case of fork 1 the design range overlaps with the system range by 80 %, which means that the possibility $P_{13\ (Fork\ 1)}$ to meet the requirement is 0.8. Using formula (7), the information content of FR_{13} equals to

$$I_{13\ (\text{Fork 1})} = \log_2 \frac{1}{0.8} = 0.32. \qquad (21)$$

In case of fork 2, $P_{13\ (Fork\ 2)} = 1$ and the information content is

$$I_{13\ (Fork\ 2)} = \log_2 \frac{1}{1} = 0. \qquad (22)$$

Thus, the information content of fork 1 is higher than that of fork 2, the latter should be become part of the design if this would not violate any constraints.

Calculations of this kind should be done for each element of a design, and the overall information content of the design as a whole should be calculated as well.

3.3. Remarks on the design process

The design presented in the previous section was not achieved at once, it is the result of a process of re-design cycles. In the first step, FR and DP hierarchies had to be made consistent, otherwise there would have been insufficient DPs or a redundant design. This was achieved through combination, decomposition and zigzagging in between FRs and DPs. Next, a first attempt was made to map in between domains, resulting in a coupled design matrix which can be found in Appendix 2. This matrix was presented to the General Manager of Third Element during the mid-term review and analysed according to two aspects: Improving design quality by adding or removing dependencies in between FRs and DPs as well as resolving coupling issues. Consequently a more detailed and rearranged design was created, which finally lead to the solution presented in **Figure 12**.

Coupling was found and resolved with the components connected to FR_{22} (low rolling resistance), FR_{33} (speed metering), FR_{35} (control of the electric drive) and FR_8 (have lighting).

The wheelset had to be moved up in the hierarchy due to coupling caused by one of its sub-components, the tyres. While tyres serve their main purpose of letting the vehicle roll, they also interfere with other functional requirements such as riding comfort and driving range. The latter created coupling in the first design matrix and therefore wheels and tyres were moved up in the hierarchy above the electric powertrain.

Speed sensors may depend either on the rear brake disc or a spoke magnet attached to the rear wheel. The disc dependent solution has the advantage that it does not require any additional parts such as magnets. However, the speed can only be measured correctly if the brake disc is designed in a way that its support stays form a fully symmetrical pattern. This is not the case with every brake disc on the market and, thus, the speed detection function has an influence on the choice of the braking system, which creates coupling. Other systems use a speed sensor that measures the spin of the rear wheel using an additional magnet attached to one of the spokes (**Figure 13**). This solution has the disadvantage that it requires more parts compared to the disc-based detection method, but the advantage of keeping braking functionality and speed metering functionality independent from each other. Following Corollary 3, the proposed design employs the spoke magnet based method, since it is more important to avoid coupling than reducing parts.

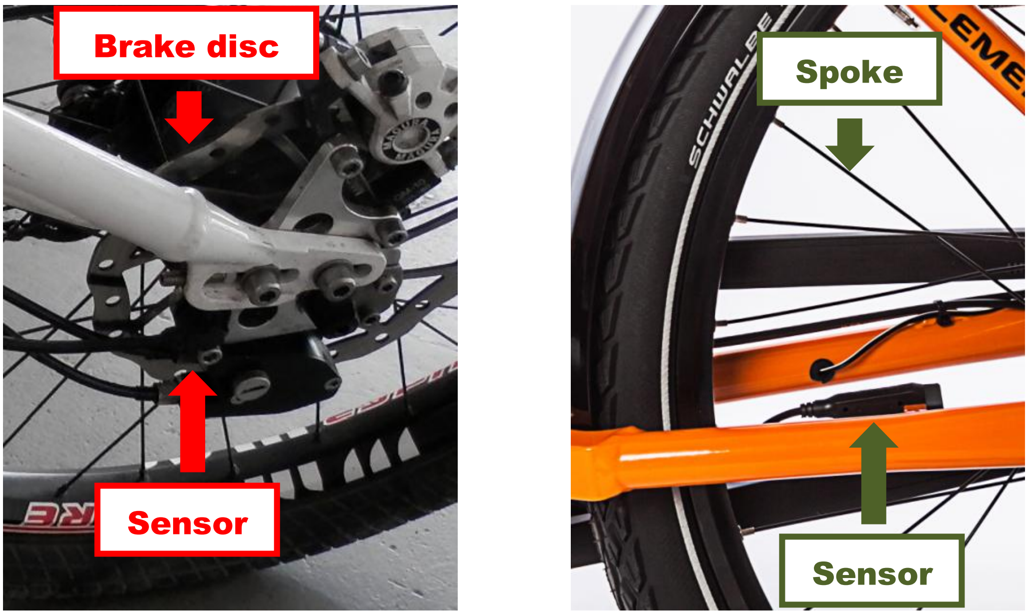

Figure 13. Speed detection systems. Left: Brake disc dependent system; Right: Spoke magnet dependent system. (Third Element 2014e, Third Element 2014f)

Prior to this study, the controller software was considered to be one part among many. Despite being the only non-physical part of the electric powertrain, the controller software came in line with other components, such as the motor/gearbox unit and the battery. Since this created coupling in between electric powertrain functions, it became evident that functions had to be rearranged. As the solution, the controller software was moved up in the hierarchy to resolve coupling. This implies that more attention should be given to controller software in future, since it is the software that makes all physical parts of the electric powertrain function together. Considering that bicycle industry is predominantly oriented in mechanical engineering, this might be challenging.

Lights and reflectors interfered with accessory parts, especially in the rear of the vehicle. The red rear light and reflectors may be mounted to the rear mud flap, to the carrier, or both of them. This results in a group of components highly dependent on each other, adding complexity to the design and leaving little choice for both designers and customers. Therefore, it is proposed to change the physical arrangement of parts in a way that three independent groups of components are created: Lighting package, mud flaps accessory package and carrier accessory package, whereas lights and reflectors mounting is done directly to the bicycle frame instead of mounting to the accessories (**Figure 14**). This ensures both physical and functional independence while still meeting legal requirements. Compatible rear lights and reflectors already exist on the market and may be supplied by Trelock (2014) and Busch & Müller (2014). Moreover, it is suggested to make these packages separately available for purchase, giving customers the possibility to choose freely in between packages when ordering their electric bicycle, thus increasing customization and adding flexibility to pricing and weight.

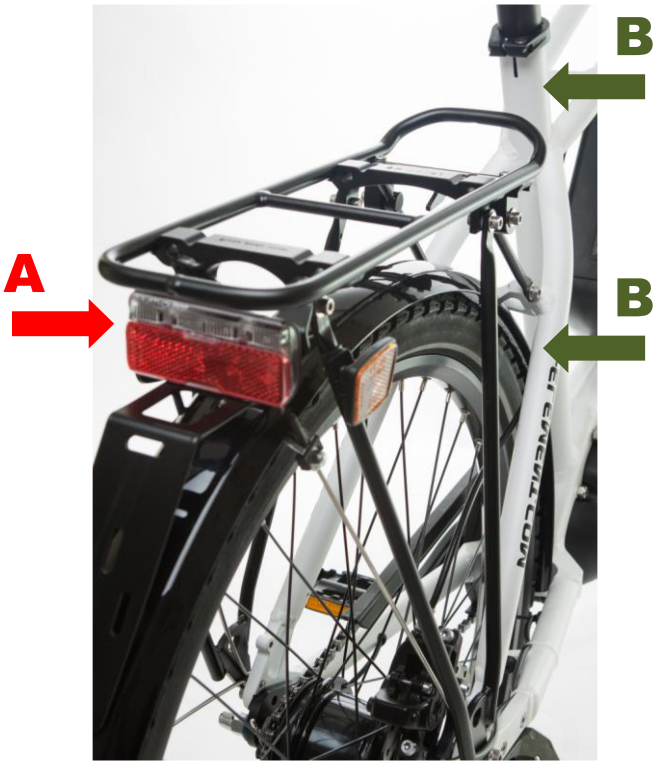

Figure 14. Mounting of the rear light. A: Mounting to the accessories; B: Proposed mounting to the frame. (Third Element 2014b)

4. RESULTS

4.1. The Axiomatic Design based Third Element electric bicycle

Figure 15. Proposed concept.(Agentura repro 2014, Ralf Bohle 2014, Electric Cyclery 2014, Selle Italia 2014, SEW-EURODRIVE 2012, SRAM 2014, Third Element 2012a, Third Element 2014d, Trelock 2014)

A concept for a novel electric bicycle was created that is defined by the following main characteristics:

- An uniquely shaped frame which clearly distinguishes the vehicle from competitor's products,
- a combination of an effective front suspension, comfortable saddle and shock absorbing tyres which provides riding comfort, even though the frame is a rigid construction,
- a gear sensor which makes shifting of gears easily possible even under load conditions, turning a major weakness of electric bicycles into an advantage,
- reduced complexity and the possibility for increased customization by a fully modular arrangement of components and component groups, especially concerning the speed detection system and accessories,
- an innovative and reliable charging system which makes charging of the battery easy and convenient and,
- additional multi-media functions for better human-machine interaction, thereby improving key functionalities such as driving range as well.

The proposed concept further comprises a rigid frame which ensures stability and gives the user a feeling of control and safety, a graphical display providing exactly defined functionality, a speed sensor without interdependencies to other component groups, and intelligent controller software which further improves a variety of performance factors.

Overall, the Axiomatic Design based electric bicycle pleases the user with a number of functions that make operation easy and full of pleasure, while still meeting legal requirements and keeping price and weight within reasonable limits. All characteristics are based on original customer feedback as well as professional expertise. The technical realization exhibits reduced dependencies and complexity.

4.2. Opportunities and limitations of Axiomatic Design with this case

All in all, Axiomatic Design showed to be of advantage to electric bicycle development at Third Element.

The application of Axiomatic Design to the case of Third Element's electric bicycle development showed to have substantial opportunities. In his feedback on the results of this study, Third Element's General Manager (2014b) pointed out that "Axiomatic Design helps to analyse the capabilities and visualizes the dependencies of the single components" and that "many mistakes can be shown at an early stadium, so time can be saved without getting these results too late in a more advanced stage". He added that fewer mistakes will be done and problematic dependencies can be avoided, especially when teams work together at different departments. Further the General Manger agreed with the starting point of the process, which is user feedback, or – in case of products or components that are completely new to the market – a mix of personal experience, market research, or pilot studies. (General Manager, Third Element (2014b.)

Limitations with the application of Axiomatic Design to this case exist, but are minor in their impact and can be dealt with. One limitation may be seen in the workload that comes with the quantitative assessment of the Information Axiom, which appears to be a well-known problem in research on complexity. Already in the 1990s, Calinescu, Efstathiou, Schirn and Bermejo (1998: 724) warned that the task of measuring complexity is time-consuming, requires a lot of involvement and might not be carried out thoroughly. Therefore, an exact calculation of the information content might exceed the resources of small companies like Third Element. As a work-around, the Information Axiom could be assessed in a qualitative way, as done by the author. Another difficulty comes with mapping from the customer domain to the functional domain, which will be dealt with in more detail in the discussion section.

5. DISCUSSION

5.1. Mapping from CAs to FRs

In the end of the results section, it was stated that difficulties occurred with mapping from the customer domain to the functional domain. The underlying reasons for this may be found in the possibly problematic nature of customer statements (cf. 2.5.7). In fact, the list of customer statements created for this research comes close to a MRS, including the difficulties that were assumed to come with it. There are some suggestions within Axiomatic Design theory on how to deal with these challenges, however there seems to be no as detailed mapping process with the customer domain as it is with other domains. This has generated many degrees of freedom for the case company manager and the author when formulating FRs, bearing the risk of misrepresenting customer statements due to human error. As a consequence, it may be necessary to extend the theoretical framework for this case. If it was possible to supplement Axiomatic Design with one or more methods from marketing or quality research, an even more analytical approach could be established that guides through the whole product development process without any lack of detail from start to finish.

5.2. Coupling

Although coupling issues had to be resolved and the final design did not result in an uncoupled but a decoupled matrix, the amount of coupling was not as extensive as could have been expected. The reason for this might lie in the organizational framework of bicycle production which clearly distinguishes in between OEMs and component manufacturers with own areas of responsibility. However, as the coupling problem in between some speed detection systems and brake systems has shown, there is still room for interference in between component groups. This especially applies to electric bicycles which have components that are new to bicycle industry. Therefore it is important indeed to be in control of functional and physical dependencies by paying attention to principles such as the Independence Axiom of Axiomatic Design.

5.3. Suggestions to keep the information content low

In the past, the case company has tried to address C_3 (creates fun) by equipping their vehicles with very powerful electric powertrains. This made it very difficult not to violate C_1 (price) and C_2 (weight), because more power usually came along with more expensive and heavier powertrain components, especially regarding the batteries. If due to the powerful powertrain the vehicle becomes a scooter style electric bike and regulations of 2002/24/EC apply, additional parts have to be added which increases the difficulty of meeting C_1 and C_2 even more. Therefore, it is suggested to create fun by other means than superior power and stay within bicycle regulations whenever possible. This will reduce complexity and make it easier to meet price and weight goals.

How can the demand for "fun" be addressed by other means than brutally strong, motorbike-standard powertrains? In fact many customers demanded for a powerful electric motor and it is also true that a powertrain which meets bicycle standards is weaker than a motorbike powertrain. However, it does not have to appear like that to the user. By using intelligent motor-control and start-up procedures, the electric propulsion can subjectively appear strong even at a 250 W power rating. Other measures may comprise improved gearshift performance, frame rigidness, drive modes and multi-media functions. In their sum, such measures may make a vehicle with a less powerful motor as appealing as a stronger one, and thereby enable electric bicycle OEMs to satisfy "fun" seeking customers while still operating within bicycle standards.

Especially with gearshift performance there is much room for future innovation. Customer feedback has shown that gearshift performance has a viable impact on the operation of electric bicycles, within the past often in a negative way. Cracking sounds, the impossibility to shift when going uphill and even damage to the drive led to disappointment of users. Resolving these issues can not only cure a weak spot of electric bicycles, moreover it has the potential to add up to the often sought „fun“ and „easy to use“ factors if addressed correctly. Possibilities are the use of internal gears that are more tolerant to shifting under load such as the NuVinci models, the direct linkage of gearshift and electric powertrain by a gear sensor, or the programming of more intelligent controller software to indirectly anticipate gearshifts and regulate electric assistance accordingly. At the time of this study, the gear sensor seemed to be the most promising option due to its availability, cost and newness to the market.

Another suggestion to reduce price and weight is to increase customization. Third Element can offer a basic vehicle that comes with a standard capacity battery and without any accessories. This reduces the number of parts and lowers complexity, thus lowering price and weight. In addition, a price level is established which makes Third Element's products accessible to customers with a comparably low spending level. Customers with comparably high spending level still have the possibility to purchase a high capacity battery or additional accessory packages to adapt the product according to their own needs and wishes. The practical implementation of this suggestion seems feasible due to the capabilities of Axiomatic Design and the Third Element's organizational structure. Axiomatic Design facilitates this approach by making it easy to add or remove components of a design by carefully paying attention to coupling. Third Element as a small company is much more flexible than mass-producers, thus having the possibility to supply customized products and gaining competitive advantage towards other OEMs with less flexible productions systems.

Finally it was learned that increasing battery capacity in order to extend driving range should be the least measure to undertake. In the past, much focus was on battery capacity when it came to driving range. Although the technical linkage in between these two factors is undeniable, there are other factors that influence driving range as well and should be taken into concern more carefully in future. Weight, top-speed, acceleration capability, controller software, gear shift, assist modes and tyre friction are just few among many factors to mention that can contribute negatively or positively to driving range and should receive more careful attention in the future. This can be done by easy measure, such as the choice of light rolling tyres, or far-reaching measures such as intelligent drive modes which automatically adapt assist ratio to the individual driving behaviour of users.

5.4. Limitations of this study

It should be noted that this research has examined only specific challenges and components affected by those challenges, which were of importance to the case company at the time the study was conducted. The design application does not follow a holistic approach towards the design of an electric bicycle, lacking functions such as steering. If a complete vehicle was designed based on this study, further research would have to be undertaken to finalize the design. The same applies to the Information Axiom, which could have been qualitatively assessed in more than one example. Further the extent to which Axiomatic Design theory was discussed was also limited, for example by leaving out aspects on the robustness of designs.

6. CONCLUSION

The collection and review of 440 individual customer statements marked the starting point for this case study. Based on the dataset, Axiomatic Design was applied to electric bicycle development at Third Element. This comprised the definition of FRs and DPs, their analytical mapping in order to create the design matrix, the formulation of PVs and constraints, as well as the discussion of the information content. As the result, a novel electric bicycle concept was presented.

Concerning the question on how an Axiomatic Design based electric bicycle is specified, it can be answered that a vehicle design following this approach is defined by six main characteristics organised in a decoupled design with reduced complexity. The main characteristics comprise a uniquely shaped frame which distinguishes the vehicle from competitor's products, while a combination of comfort elements ensure pleasant riding capabilities. Further the use of a gearshift sensor and the possibility for an inductive charging system are innovative features which pave the way to the future. In addition to that, flexible accessory packages and additional multi-media functions broaden the customer base and contribute to better human-machine interaction. The Independence Axiom is taken into account by a fully modular arrangement of components, leading to the additional benefit of numerous possibilities for customization. The Independence Axiom has also helped to resolve existing and future coupling problems. The qualitative use of the Information Axiom has led to reduced overall complexity.

The question on the opportunities and limitations of Axiomatic Design with this case was addressed by the collection of feedback from the case company as well as the critical reflection of the design process. It can be concluded that Axiomatic Design bears substantial advantages to electric bicycle development, especially towards two aspects: First, Axiomatic Design helps to translate customer requirements into product specifications by providing an all-encompassing design framework. Second, analytical methods within this framework visualize dependencies in between components of the design. Both aspects together support designers in creating products that meet customer expectations better and require less rework during the development process. Difficulties occurred with the processing of customer statements and the quantitative application of the Information Axiom. With customer statements it was challenging to manually translate them into FRs due to their large number. The quantitative assessment of the information axiom was difficult to realize due to the in-depth system knowledge required on the one hand, and limited resources on the other hand.

In the larger context, the Axiomatic Design approach taken in this study may lead to generally increased problem awareness in the early phases of electric bicycle development projects. The method was proven to be practical enough for application in a real world context, and tools like the design matrix give product designers the possibility to detect potential issues earlier in the design process than usual. Especially with small and medium size companies, this ability is crucial for success.

Taking into account the challenges identified with mapping from the customer domain to the functional domain, future research may investigate how to combine Axiomatic Design with methods that enable effective processing of large amounts of customer data. If this was possible, the result would contribute towards an even broader framework for analytical product and service design.

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APPENDIX 1. Complete list of customer statements

Table 11. Complete list of customer statements.

Id.	Source	Vehicle or Component	Date	Customer Type	Feedback
1	Physical folder "Messen 3E 2012"	eSpire / eSpire Comp	08.12	Business	"In Australien sind max. 200W erlaubt"
2		eSpire / eSpire Comp	08.12	Business	"Interesse an Flottenlösungen"
3	Physical folder "Sales - Messekontakte"	eSpire / eSpire Comp	08.11	Business	"Interesse an Pedelec 25km/h. Mit Batterie im Oberrohr."
4		eSpire / eSpire Comp	08.11	Business	"E-Bike laden, interessieren sich für 45 km/h Version"
5		eSpire / eSpire Comp	08.11	Business	"Zu teuer!"
6		eSpire / eSpire Comp	08.11	Business	"Zweifelt am Preis."
7		eSpire / eSpire Comp	08.11	Business	"Möchte 45 km/h"
8		eSpire / eSpire Comp	08.11	Business	"Sucht Mofa-/Mopedklassebikes für Benelux"
9		eSpire / eSpire Comp	08.11	Business	"Speedversion gefragt. Preislevel muss besser sein. Von Optik angetan."
10		eSpire / eSpire Comp	08.11	Business	"Nicht uninteressiert (an E-Bikes)"
11		eSpire / eSpire Comp	08.11	Business	"Kein Interesse."
12		eSpire / eSpire Comp	08.11	Business	"Ist begeistert."
13		eSpire / eSpire Comp	08.11	Business	"Kein Interesse an E-Bikes"
14		eSpire / eSpire Comp	08.11	Business	"Aus Prinzip keine E-Bikes"
15		eSpire / eSpire Comp	08.11	Business	"Zu teuer!"
16		eSpire / eSpire Comp	08.11	Business	"Klasse, aber zu teuer. Obergrenze 7000-7500"
17		eSpire / eSpire Comp	08.11	Business	"Hat Bedenken bez. Preis"
18		eSpire / eSpire Comp	08.11	Business	"Zu teuer!"
19		eSpire / eSpire Comp	08.11	Business	"Preis!"
20		eSpire / eSpire Comp	08.11	Business	"Kein Gasgriff!"

21		eSpire / eSpire Comp	08.11	Business	"Möchte offene Version, weil in Russland kein Limit besteht"
22		eSpire / eSpire Comp	08.11	Business	"Begeistert vom Ansprechverhalten"
23		eSpire / eSpire Comp	08.11	Business	"Rücklichthalter ohne Nummernschild"
24		eSpire / eSpire Comp	09.11	Business	"Guter Anzug, Leichtläufig, Gute Kurvenlage"
25		eSpire / eSpire Comp	09.11	Business	"Bordcomputer fehlt, ist Standard selbst bei billigen E-bikes"
26		eSpire / eSpire Comp	09.11	Business	"Guter Motoranzug, Abrieglung sollte nicht so Abrupt sein."
27		eSpire / eSpire Comp	09.11	Business	"Sucht E-Bike für Funsektor mit mehr Leistung"
28		eSpire / eSpire Comp	09.11	Business	"Ist voll begeistert."
29		eSpire / eSpire Comp	09.11	Business	"Starker Anzug, leider bei 45km/h begrenzt"
30		eSpire / eSpire Comp	09.11	Business	"Gute Optik, Gute Fahreigenschaften 45kmh, Gewicht schlecht, Preis schlecht, 3-Gang Nabe würde genügen, 45kmh sind noch zu wenig."
31		eSpire / eSpire Comp	09.11	Business	"Fahrspaß pur, durch Mittelmotor starker Verzug der Schwinge, tolle Optik."
32		eSpire / eSpire Comp	09.11	Business	"E-Spire Comp UVP2-3k€"
33		eSpire / eSpire Comp	09.11	Business	(-) Hinterbau hat Lastwechselreaktionen, (-) zu schwer, (-) zu teuer, (+) hohes Drehmoment, (++) hoher Fahrspaß
34		eSpire / eSpire Comp	09.11	Business	(+) Antriebsstark, (+) Treten Nebensache, (-) Verwindung E-Antrieb hinten (Dämpfer)
35		eSpire / eSpire Comp	09.11	Business	(+) Kompatibel mit Parts, (+) Power Beschleunigung, (+) Design, (-) Preis
36		eSpire / eSpire Comp	09.11	Business	(-) unstabil bei schnellen Lastwechseln, (-) vibrieren Vorderrad bei hoher Geschw.
37		eSpire / eSpire Comp	09.11	Business	"Display muss sein, Akku frostgefährdet?"
38	Physical folder "Messen - Motorrad, Fahrrad, Freizeit"	eSpire / eSpire Comp	09.11	Business	"E-Spire als Promo für Tankstellen."
39	Phsical folder "Presse Leads"	eSpire / eSpire Comp	05.10	Business	"Design super"

40		eSpire / eSpire Comp	05.10	Business	"Eigene E-Spire Helme denkbar."
41		eSpire / eSpire Comp	05.10	Business	"Schönstes Bike hier, Preis unter 5k€, kein Nummernschild."
42	Test drive evaluation "Pure 25 1"	Overall	07.13	Consumer	"Sportliches Pedelec, besonders hart und unkomfortabel. Der Motor schafft auch lange Steigungen, ohne merklich nachzulassen. Nur mit kleinen 26-Zoll-Reifen erhältlich. Passable Bremsen."
43		Usage	07.13	Consumer	(+) "Handliches Fahrrad mit 26-Zoll Rädern. Die Kette ist vollständig verkleidet, so gibt es keine eingeölten Hosen. Vorderradgabel wackelt leicht."
44		Motor	07.13	Consumer	(+) "Der Motor hat eine Anfahrhilfe, bei der das Fahrrad sofort Geschwindigkeit aufnimmt. Die ist auch beim Bergaufschieben des 24 kg schweren Fahrrades angenehm."
45		Motor	07.13	Consumer	(+) "Zieht kräftig an, der eingelegte Gang muss dabei zur Geländesituation passen (8 Gänge)."
46		Motor	07.13	Consumer	(-) "Das Treten wird über 25 km/h recht schwer."
47		Transmission	07.13	Consumer	(+) "Die acht Gänge der Nabenschaltung sind gut übersetzt und in der Anzahl völlig ausreichend für die maximal erlaubten motorunterstützten 25 km/h."
48		Transmission	07.13	Consumer	(0) "Die Nabenschaltung benötigt beim Wechseln der Übersetzung eine kurze Trittunterbrechung, sonst rasten die Gänge nicht ein. Deshalb sollte sich der Radler bereits vor dem Erklimmen eines Berges für den geeigneten Gang entscheiden."
49	Test drive evaluation "Pure 25 2"	Brakes	07.13	Consumer	(-) "Die Bremsen benötigen ordentlich Kraft an den Hebeln, um für passable Verzögerung zu sorgen."
50		Comfort	07.13	Consumer	(--)"Extrem unkomfortabel, der Radler springt und hüpft auf schlechter Straße über die Unebenheiten, sitzt dabei auf einem eisenharten Sattel. Die Vorderradfederung zeigt keine erkennbare Wirkung."

51		Interface	07.13	Consumer	(-) "Etwas umständliche Bedienung, Display mit wenig Kontrast, Einstellung mit Sonnenbrille kaum erkennbar."
52		Carrying	07.13	Consumer	(0) "Die oberen Rahmenröhrchen haben eine recht bequeme Höhe zum Anheben, die insgesamt 24 kg Gesamtgewicht sind gut austariert."
53		Sound	07.13	Consumer	(+) "Das dezente Motorsummen stört kaum."
54	Test drive evaluation "Trail40 1"	Trail 40	11.13	Consumer	(+) "Das Bike liegt satt und straff auf der Straße und vermittelt einem ein sicheres Fahrgefühl"
55		Trail 40	11.13	Consumer	(+) "Das Bike fühlt sich grundsätzlich sportlich und agil an, im durchschnittlichen Gelände…"
56		Trail 40	11.13	Consumer	(+) "Die Bremsen sind stark genug das schnelle und doch schwere Bike zu zügeln"
57		Trail 40	11.13	Consumer	(+) "Das Bike ist gefühlt 'rattenschnell'"
58		Trail 40	11.13	Consumer	"Die Möglichkeit richtig selbst zu bestimmen wie viel ich mitwirkte (also selbst mit Treten beisteure) hat für mich nicht optimal funktioniert, d.h. wenn ich nicht trete verliere ich an Speed, wenn ich trete dann geht das Bike ab wie ne Rakete…"
59		Trail 40	11.13	Consumer	(-) "Der Akku ist viel, viel, viel zu schnell leer (gefühlt bei guter Last, ca. 20 Km), das ist unakzeptabel."
60		Trail 40	11.13	Consumer	"Übrigens, die Treppen von der Schlossberghalle auf die Hauptstraße herunter die hat das Bike auch gut gemeistert."
61	Test drive evaluation "Trail40 2"	Trail 40	11.13	Consumer	(+) "Grundsätzlich hat sich das Bike noch überall fahren lassen"
62		Trail 40	11.13	Consumer	(+) "Die Bremsen waren immer noch ausreichend gut, obwohl du ihnen schon die Last (Gefälle, Eigengewicht, Fahrgewicht) angemerkt hast."
63		Trail 40	11.13	Consumer	(-) "Das Bike schiebt bei steilem Bergabpassagen mit seinen 25 kg schon gewaltig, d.h. der Fahrer muss hier sehr sensibel die Bremsen zwischen vorne und hinten dosieren, auf Schotterstrecke eine echte Herausforderung."

64		Trail 40	11.13	Consumer	(-) "Bergauf musste ich trotz voller Unterstützung sehr stark mithelfen, d.h. für richtig knackige Bergaufpassagen scheint mir das Bike ungeeignet, das liegt wohl am hohen Eigengewicht und aus meiner Sicht an der Schaltübersetzung, die ist für solche Steigungen einfach nicht ausgelegt."
65		Trail 40	11.13	Consumer	"Der Akku war auch hier sehr schnell leer, ich musste meine Isartour von sonst 30 auf 17 Km abkürzen."
66		Trail 40	11.13	Consumer	"Eine tolle Erfahrung, ein interessantes und doch sportliches eBike, jedoch für meine etwas hohen Geländeanforderungen nicht geeignet. Und die Akkulaufzeit sollte auch bei Volllast doch 40-50 Km reichen."
67	Sales feedback "Feedback Vertrieb BeNeLux 2013 03"	Pure25	03.13	Business	"Lackierung am besten keine Pulverbeschichtung da zu sehr Schmutzempflindlich und nicht Pflegeleicht. Der Dreck zieht in die Poren."
68		Pure25	03.13	Business	"Alle 3E-Produkte sind im hohen Preissegment (>2000€) und sollten daher folgende Komponenten beinhalten bei den Pure (unabhängig ob 25 oder 45): Großes Display mit entsprechende Info (das kleine Display wirkt zu mickrig) und wenn im Vergleich zu Bosch-Motoren gearbeitet wird, haben diese alle das sehr vernünftige große Bosch-Display."
69		Pure25	03.13	Business	"…Diebstahlsicherung am Hinterrahmen (z.B. Abus))"
70		Pure25	03.13	Business	"Die Schweißnähte sollten feiner bearbeitet sein."
71		Pure25	03.13	Business	"Das hintere Schutzblech sollte besser befestigt sein."
72		Pure25	03.13	Business	"Das Kabel des Rücklichts sollte besser eingearbeitet sein."
73		Pure25	03.13	Business	"Im Wesen sollten alle Bikes mit 12Ah-Batterie kommen."
74		Product: Trail	03.13	Business	"Knick-Bewegung nach Innen beim Bremsen der Vordergabel (Passung im Rahmen zu groß?)"
75	Trade fair feedback "Feedback Eurobike	Pedelec 25	08.11	?	(+) "Keine Tretkraft und trotzdem Vollgas möglich"

76	2011"	Pedelec 25	08.11	?	(+) "Starker Anzug des Motors"
77		Pedelec 25	08.11	?	(+) "Durchzugskraft, lineare Leistung, Fahrspaß"
78		Pedelec 25	08.11	?	(+) "Nuvinci super zum Antriebskonzept (Extra Energy)"
79		Pedelec 25	08.11	?	(+) "Konzept nicht schlecht, jeder, der das Rad fährt."
80		Pedelec 25	08.11	?	(+) "Wird es früher oder später haben wollen (Extra Energy)"
81		Pedelec 25	08.11	?	(+) "Anfahren am Berg +10"
82		Pedelec 25	08.11	?	(+) "Leistung gut"
83		Pedelec 25	08.11	?	(+) Gleichmäßige Beschleunigung"
84		Pedelec 25	08.11	?	(+) "Gut zu fahren"
85		Pedelec 25	08.11	?	(0) "Display o.k., aber einfach (Extra Energy)"
86		Pedelec 25	08.11	?	(0) "Preis o.k."
87		Pedelec 25	08.11	?	(-) "25km/h Begrenzung"
88		Pedelec 25	08.11	?	(-) "25km/h Begrenzung"
89		Pedelec 25	08.11	?	(-) "Vmax zu gering"
90		Pedelec 25	08.11	?	(-) "Tretlagersensor fehlt"
91		Pedelec 25	08.11	?	(-) "Hinterbau weich"
92		Pedelec 25	08.11	?	(-) "Hinterbau schwammig"
93		Pedelec 25	08.11	?	(-) "Hinterbausteifigkeit"
94		Pedelec 25	08.11	?	(-) "Motorgeräusch störend"
95		Pedelec 25	08.11	?	(-) "Zubehör anbieten! Vorbild smart."
96		eSpire KBA 45	08.11	?	(+) "Gute Leistung"
97		eSpire KBA 45	08.11	?	(+) "Gute Bremsen"
98		eSpire KBA 45	08.11	?	(+) "Brachiale Gewalt"
99		eSpire KBA 45	08.11	?	(+) "Gutes Fahrverhalten"
100		eSpire KBA 45	08.11	?	(+) "Fahrwerkskomfort"
101		eSpire KBA 45	08.11	?	(+) "Fahrspaß"
102		eSpire KBA 45	08.11	?	(+) "Optik"
103		eSpire KBA 45	08.11	?	(+) "Beschleunigung"
104		eSpire KBA 45	08.11	?	(+) "1200W"
105		eSpire KBA 45	08.11	?	(+) "Sehr gutes Fahrgefühl"
106		eSpire KBA 45	08.11	?	(+) "Fährt gut, guter Abzug, Hupe gut für Leute, die im Weg sind."
107		eSpire KBA 45	08.11	?	(+) "Very cool"
108		eSpire KBA 45	08.11	?	(+) "Power, Spaß, Design"
109		eSpire KBA 45	08.11	?	(+) "Gasgriff geht normalerweise nicht, hier aber sinnvoll (Extra Energy)"
110		eSpire KBA 45	08.11	?	(+) "Erster Eindruck: Krass, gutes Ansprechen der ezl. Gänge, Hupe lustig"
111		eSpire KBA 45	08.11	?	(+) "Gute Bremsen, Drehmoment im Vgl. mit Benziner gut."

112		eSpire KBA 45	08.11	?	(+) "7000 Euro realistischer Preis"
113		eSpire KBA 45	08.11	?	(+) "Kein Vergleich zu sonstigen Bikes"
114		eSpire KBA 45	08.11	?	(+) "Für schotteriges Gelände o.k."
115		eSpire KBA 45	08.11	?	(+) "Starker Motor"
116		eSpire KBA 45	08.11	?	(0) "Mehr Motorrad als Fahrrad"
117		eSpire KBA 45	08.11	?	(-) "Keine Pedelecfunktion"
118		eSpire KBA 45	08.11	?	(-) "Schwinge verzieht sich beim Anfahren"
119		eSpire KBA 45	08.11	?	(-) "Keine kleinen Rahmengrößen
120		eSpire KBA 45	08.11	?	(-) "Wendigkeit"
121		eSpire KBA 45	08.11	?	(-) "Drehmoment"
122		eSpire KBA 45	08.11	?	(-) "Schaltung zu kurz übersetzt"
123		eSpire KBA 45	08.11	?	(-) "Rohloff"
124		eSpire KBA 45	08.11	?	(-) "Pedelecfunktion fehlt"
125		eSpire KBA 45	08.11	?	(-) "Bodenfreiheit"
126		eSpire KBA 45	08.11	?	(-) "Low rigidity of the rear frame"
127		eSpire KBA 45	08.11	?	(-) "Gewicht"
128		eSpire KBA 45	08.11	?	(-) "Zu schwer fürs Gelände"
129		eSpire KBA 45	08.11	?	(-) "Bodenfreiheit"
130		eSpire KBA 45	08.11	?	(-) "Schwingendrehpunkt"
131		eSpire KBA 45	08.11	?	(-) "Keine Pedelecfunktion"
132		eSpire KBA 45	08.11	?	(-) "Nicht für Training geeignet"
133		Not specified	08.11	?	(+) "Aussehen"
134		Not specified	08.11	?	(+) "Anzug/Beschleunigung"
135		Not specified	08.11	?	(+) "Bequemlichkeit"
136		Not specified	08.11	?	(+) "Fun Faktor +++"
137		Not specified	08.11	?	(+) "Handling ++"
138		Not specified	08.11	?	(+) "Bremse +++"
139		Not specified	08.11	?	(+) "Antrieb ++"
140		Not specified	08.11	?	(+) "Feedback wird über 3E Blog gegeben"
141		Not specified	08.11	?	(+) "Super nettes Personal"
142		Not specified	08.11	?	(+) "Sportive Modelle"
143		Not specified	08.11	?	(+) "Krasse Beschleunigung"
144		Not specified	08.11	?	(+) "Wahnsinns Feeling! :)"
145		Not specified	08.11	?	(-) "Preis"
146		Not specified	08.11	?	(-) "Gewicht"
147	Sales feedback "Feedback Grosshandel 2013 01"	Pure 25 / Trail 45	01.13	Business	(+) "Handgemachte Rahmen aus Karlsruhe und auch sonst direkt aus Deutschland."

148		Pure 25 / Trail 45	01.13	Business	(+) "Besonders bei den Händlern kam das Pure 25 sehr gut an. Mit 3500€ ist es nur 500€ über dem Preis eines taiwanesischen Rades, zumindest wenn man was schickes nimmt. Dennoch dürfen wir uns nichts vormachen, es ist ein hochpreisiges Rad. Gerade der Handel ist da oft sehr zurückhaltend."
149		Pure 25 / Trail 45	01.13	Business	(+) "Neueinsteiger im Handel wollen meistens vorsichtig anfangen. Ich empfehle dann das Pure 25 und das Trail 45 als Erstbestellung."
150		Pure 25 / Trail 45	01.13	Business	"Etwas Sorgen mache ich mir bei der Reichweite. In der schnellen Variante dürfte das Rad wohl keine 20 Kilometer weit reichen. Hier muss man mal testen bzw. Schauen, ob es andere Akkumodifikationen gibt."
151		Pure 25 / Trail 45	03.13	Business	"MPF Motor nicht bekannt und „fährt sich nicht so harmonisch wie ein Bosch“"
152		Pure 25 / Trail 45	03.13	Business	"50 km Reichweite ist zu wenig – zumindest die Angabe -> ist ein absolutes KO Kriterium"
153		Pure 25 / Trail 45	03.13	Business	"Schlechtes Display momentan – zu wenig Funktionen und Informationen - brauchen auf den Vorführern dringend die neuen Displays"
154		Pure 25 / Trail 45	03.13	Business	"Im Moment keine Nuvinci bei den Pure verbaut"
155		Pure 25 / Trail 45	03.13	Business	"Hoher Preis für das was geboten wird"
156		Pure 25 / Trail 45	03.13	Business	"USP vom MPF Motor herausarbeiten"
157		Pure 25 / Trail 45	03.13	Business	"Aktuelle Versionen schnell hierhaben"
158		Pure 25 / Trail 45	03.13	Business	"USP vom Fahrzeug selbst noch etwas hervorheben"
159	Trade fair feedback "Feedback Messe HappyBikeDays Houffalize 2013 04"	Pure25	04.13	Consumer	(+) "Design, praktisch, einfach"
160		Espire	04.13	Consumer	(+) "Looks, Unterstützung"
161		Espire	04.13	Consumer	(+) "Design, Beeindruckend, Moto-Look"
162		Espire	04.13	Consumer	(+) "Fun, Gabel von DH"
163		Espire	04.13	Consumer	(+) "Gutes Handling, angemessene Geschwindigkeit"

164		Espire	04.13	Consumer	(+) "Angenehme Erfahrung. Gute Unterstützung"
165		Espire	04.13	Consumer	(+) "Unglaublicher Power, angenehme Erfahrung"
166		Espire	04.13	Consumer	(+) "Unterstützung, Agil"
167		Pure25	04.13	Consumer	(+) "Geniale Unterstützung, angenehme Fahrerfahrung. Gute Fahrposition"
168		Pure25	04.13	Consumer	(+) "Gute Effizienz, gutes Handling"
169		Pure25	04.13	Consumer	(+) "Gute Unterstützung beim flach fahren"
170		Trail 40	04.13	Consumer	(+) "Effizienz, Unterstützung"
171		Trail 40	04.13	Consumer	(+) "Schnell uphill, gute Übersetzung"
172		Trail 40	04.13	Consumer	(+) "Leistung, Design, Top-Geschwindigkeit"
173		Trail 40	04.13	Consumer	(+) "Gute erste Erfahrung mit E-Bike, gute Geschwindigkeit"
174		Trail 40	04.13	Consumer	(+) "Genial, gute Vorschritt, angenehme Erfahrung"
175		Trail 40	04.13	Consumer	(+) "Einfach zu verwenden auch mit kleine Unterstützung. Höchstgeschwindigkeit"
176		Trail 40	04.13	Consumer	(+) "Schönes Design, verschiedene Unterstützungsmodi, erstaunliche Gangwechsel"
177		Trail 40	04.13	Consumer	(+) "Kraft, Komfort, Bremsen"
178		Trail 40	04.13	Consumer	(+) "Leichte Unterstützung, gute Stoßdämpfer"
179		Trail 40	04.13	Consumer	(+) "Unterstützung, Geschwindigkeit, einfach"
180		Trail 40	04.13	Consumer	(+) "Gute sanfte Schaltung, gute Unterstützung"
181		Trail 25	04.13	Consumer	(+) "Gute Unterstützung auf dem Flachen"
182		Trail 25	04.13	Consumer	(+) "Motor"
183		Trail 25	04.13	Consumer	(+) "Schnell und einfach ein zu stellen. Schönes Modell"
184		Trail 25	04.13	Consumer	(+) "Aufhängung, Design, Gangwechsel"
185		Trail 25	04.13	Consumer	(+) "Fun-Bike, gutes Handling"
186		Trail 25	04.13	Consumer	(+) "Unterstützung, fast überall durchs Gelände, gute Aufhängung"
187		Trail 25	04.13	Consumer	(+) "Effizienz"
188		Trail 25	04.13	Consumer	(+) "Komfort, Einfachheit, Spaß"
189		Trail 25	04.13	Consumer	(+) "Look, Unterstützung auf flache Bahn"
190		Trail 25	04.13	Consumer	(+) "Gute Unterstützung, gute Stoßdämpfer, einfache Bedienung"

191		Pure25	04.13	Consumer	(-) "Kein off-road"
192		eSpire	04.13	Consumer	(-) "Blockierung"
193		eSpire	04.13	Consumer	(-) "Rohloff Schaltung, Anhalten um Gänge zu wechseln"
194		eSpire	04.13	Consumer	(-) "Zu wenig Power, schlechte Schaltung"
195		eSpire	04.13	Consumer	(-) "Keine Regeneration"
196		eSpire	04.13	Consumer	(-) "Schwer schalten"
197		eSpire	04.13	Consumer	(-) "Gewöhnungsbedürftig"
198		eSpire	04.13	Consumer	(-) "Rohloff Schaltung"
199		Pure25	04.13	Consumer	(-) "Nicht sanft treten, Schaltung"
200		Pure25	04.13	Consumer	(-) "Hartes Sattel"
201		Pure25	04.13	Consumer	(-) "Am meisten wird Sport-Modus verwendet"
202		Pure25	04.13	Consumer	(-) "Unzureichend Berg hoch"
203		Trail 40	04.13	Consumer	(-) "Batterie"
204		Trail 40	04.13	Consumer	(-) "Gewicht, keine Regeneration"
205		Trail 40	04.13	Consumer	(-) "Ohne Batterie gefallen während der Fahrt und war dann sehr schwer"
206		Trail 40	04.13	Consumer	(-) "Gewicht"
207		Trail 40	04.13	Consumer	(-) "Preis"
208		Trail 40	04.13	Consumer	(-) "Zugänglichkeit und Ausbau der Batterie, teuer"
209		Trail 40	04.13	Consumer	(-) "Gewicht, Preis"
210		Trail 40	04.13	Consumer	(-) "Bodenfreiheit"
211		Trail 40	04.13	Consumer	(-) "Gewicht Berg hoch"
212		Trail 25	04.13	Consumer	(-) "Keine Unterstützung bei steile Fahrten"
213		Trail 25	04.13	Consumer	(-) "Gewicht"
214		Trail 25	04.13	Consumer	(-) "Langsam beim anfahren, schwer, kein Display"
215		Trail 25	04.13	Consumer	(-) "5 bis 10 kg zu schwer, fehlt lockout für den hinteren Stoßdämpfer"
216		Trail 25	04.13	Consumer	(-) "Nicht ausreichend berghoch"
217		Trail 25	04.13	Consumer	(-) "Gewicht, Bremsen"
218		Trail 25	04.13	Consumer	(-) "Schwer, keine Unterstützung Berg hoch"
219		Trail 25	04.13	Consumer	(-) "Gewicht"
220		Pure25	04.13	Consumer	"Gut entwickelt"
221		Trail 40	04.13	Consumer	"Bremsen umgekehrt, gefährlich wenn nicht mitgeteilt"
222		Trail 25	04.13	Consumer	"Erste E-Bike Erfahrung und gut"
223		Trail 25	04.13	Consumer	"Gut für Leute die etwas Unterstützung brauchen. Gutes Konzept"

224		Trail 25	04.13	Consumer	"Keine Begründung kein Fahrrad mehr zu fahren "
225	Sales feedback "Feedback Händler 2013 03"	Pure/Trail	03.13	Business	"Federgabel soll Lock am Lenker haben"
226		Pure/Trail	03.13	Business	"Schutzbleche müssen entweder gut sein, oder gar keine"
227		Pure/Trail	03.13	Business	"Griffe müssen gut sein"
228		Pure/Trail	03.13	Business	"Entgraten nach dem Lackieren und nicht erst beim Händler"
229		Pure/Trail	03.13	Business	"Sattelstütze bekommt sehr schnell Kratzer, Problem bei Probefahrten"
230		Pure/Trail	03.13	Business	"USP ist der Rahmen (+)"
231		Pure/Trail	03.13	Business	"Anbauteile sind 0815 (-)"
232		Pure/Trail	03.13	Business	"Vergleichbarkeit mit anderen Bikes (z.B. Stromer, AVE, Haibike, Riese und Müller) im Preissegment 3 500 - 4 500 € ist fraglich"
233	Trade fair feedback "FeedbackEurobike Sept 2011 Antriebe extern"	All CM / 3E	09.11	Consumer	"Die Nuvinci konnte man auf dem Espire in einem Prototypen Probefahren, harmonierte klasse mit dem Clean-Mobile-Antrieb. Es wird jetzt auch eine abgespeckte Version als Pedelec und S-Pedelec angeboten."
234		All CM / 3E	09.11	Consumer	"Die Clean Mobile Antriebe sind sehr kräftig, bei zu kleinem Gang kommt beim Anfahren ohne pedalieren das Vorderrad hoch"
235		All CM / 3E	09.11	Consumer	"Das Corratec eBow hat leider keine Straßenzulassung (Bild). Wäre doch etwas für unsere Speed-Junkies um A.D."
236		Bosch drive	09.11	Consumer	"Beweist wie hässlich die meisten Bosch-Pedelec sind - Motor zumeist unten (Ausnahme Hai) wie eine Tumorgeschwulst drangeklebt und der Akku - mit den Panasonic in Konkurrenz um den hässlichsten Kloben"
237		Bosch drive	09.11	Consumer	"Am Bosch-Stand gibts einen aufgeschnittenen Motor, der so schön "nackt" in meinen Augen ein Schmuckstück deutscher Ingenieurskunst ist - wertig, gut verarbeitet und aufgeräumt."
238		Bosch drive	09.11	Consumer	"Der Ave XHybrid fährt sich super, wobei der Bosch-Antrieb deutlich leiser war als bei den ersten Exemplaren, die ich gefahren bin."

239		Bosch drive	09.11	Consumer	"Der schnelle Bosch ist auch wirklich super, genauso super wie der 25km/h schnelle, rockt aber locker auf über 40 ;-)"
240		Bosch drive	09.11	Consumer	"Der Bosch Motor war laut und unangenehm im Geräusch."
241		Bosch drive	09.11	Consumer	"Die 45 Bosch sind super, mit gut Mittreten sind 45km/h drin, bei gemütlichem Treten kommt man aber auch auf knapp über 40km/h."
242		Bosch drive	09.11	Consumer	"Bei Bosch wird einem bei der höchsten Unterstützungsstufe fast jede eigene Kraftanwendung abgenommen, außer man fährt schneller, als 27 km/h."
243		Bosch drive	09.11	Consumer	"Der schnelle Bosch hat mir sehr gut gefallen, fand ihn auch nicht laut, allerdings ist das Vibrieren in der Kurbel weiterhin spürbar."
244		BionX drive	09.11	Consumer	"Die Kunden haben allerdings viel über Bionx diskutiert. Scheinen nach wie vor begeistert zu sein, was ich nicht verstehen kann, wenn ich hier im Forum über dauernde Softwareprobleme lese."
245		BionX drive	09.11	Consumer	"Was ich ja absolut super fand ist der Vorderradantrieb den Bionx gebastelt hat (gibt es erstmal nur in Diamanträdern)."
246		TransX drive	09.11	Consumer	"Also der neue TranzX Mittelmotor war für mich der größte Reinfall... schwach laut und furchtbare Regelung..."
247		TransX drive	09.11	Consumer	"Leider ist Geräuschentwicklung und Fahrdynamik nicht so wie man es erwarten könnte. War vom Antrieb recht enttäuscht."
248		TransX drive	09.11	Consumer	"Beim TranzX Mittelmotor mit 2-3 Kettenblättern ist offenbar noch viel Arbeit notwendig bis zur Serienreife."
249		Stromer drive	09.11	Consumer	"Den Stromer (45 km/h) bin ich gefahren, hervorragender Antrieb! Die S-Zulassung für D bekommen sie angeblich in drei Wochen"
250		Ghost	09.11	Consumer	"Ghost hat schöne E-Mountainbikes, allerdings mit Nabenantrieb und zunächst erstmal nicht das Konzept (endure) vom letzten Jahr."

251		Ghost	09.11	Consumer	"I was hoping to see a production ready Ghost Ndure this year, but they have decided to put it on ice for now…"
252		Cube	09.11	Consumer	"Cube hat optisch sehr gelungene Räder mit Direktantrieb und im Sattelrohr eine Batterie"
253		Cube	09.11	Consumer	"Das Cuba-rad sieht wirklich schick aus, fährt sich auch ganz gut, aber es bremst an der Unterstützungsgrenze ab. Komisches Gefühl."
254	Internal evaluation "Wettbewerbsanalyse 3E Feb.13 HS RT."	Model line-up	02.13	Internal	"Durch das eigenständige Rahmendesign differenziert sich THIRD ELEMENT deutlich, und ermöglicht dem Kunden Individualität zu leben. "
255		Model line-up	02.13	Internal	"Wie in der Anwendung der E - Bikes bedient sich THIRD ELEMENT auch im Motorkonzept höchst möglicher Effizienz. "
256		Model line-up	02.13	Internal	"Der verbaute Mittelmotor generiert 250 bzw. 500W, d.h. der Kunde kann pro Modell zwischen einem zulassungsfreien 25km/h einem 45km/h E – Bike wählen."
257		Model line-up	02.13	Internal	"Das Produktbild runden ausgesuchte Qualitäts - Lieferanten im Bereich der Anbauteile ab."
258		Unique Selling Points	02.13	Internal	"Eigenständiges unverwechselbares Rahmendesign"
259		Unique Selling Points	02.13	Internal	"Hoher Wiedererkennungsfaktor"
260		Unique Selling Points	02.13	Internal	"Hohe Differenzierung zu Wettbewerbsprodukten"
261		Unique Selling Points	02.13	Internal	"Hohe Individualität für den Kunden"
262		Unique Selling Points	02.13	Internal	"Vielseitige Einsatzmöglichkeiten / hoher Nutzwert"
263		Unique Selling Points	02.13	Internal	"Qualitativ hochwertig, Premium"
264		Unique Selling Points	02.13	Internal	"Made in Germany (Produktionstiefe in D >75%)"
265		Drive Technology	02.13	Internal	"Antrieb geräuscharm und kräftig, optisch formschöner integrierbar als Wettbewerb"
266		Drive Technology	02.13	Internal	"Platzierung des Akku nicht hinter dem Sitzrohr führt zu einem fahrradüblichen Radstand, nicht wie beispielsweise bei Panasonic zu

					überlangen Fahrrädern."
267		Drive Technology	02.13	Internal	"Akku wird künftig vom renommierten BMZ produziert, „made in Germany“."
268		Drive Technology	02.13	Internal	"Ab ca. April ist das AF Display erhältlich, mit grafischer Darstellung der wichtigsten Fahrfunktionen. Zusätzlich USB Ladeschnittstelle und Pulsmessung und Trittfrequenz."
269		Drive Technology	02.13	Internal	"Akkus mit geringerer Kapazität sind bei entsprechender Nutzung sinnvoller als überdimensionierte Akkus, die immer nur zu einem Bruchteil entladen werden. Standardakku 9 Ah, gegen Aufpreis 12 Ah erhältlich."
270		Drive Technology	02.13	Internal	"Rahmendesign und -aufbau auf den Mittelmotor konzipiert, kein bloßes Aufrüsten eines Fahrradrahmens auf Elektroantrieb – hier ist der Markt wegen fehlender Stabilität und der entsprechenden Berichterstattung der Medien verunsichert."
271		Drive Technology	02.13	Internal	"Antriebstechnik ist schnörkellos und auf das Wesentliche reduziert – keine riesigen, schwer zu bedienenden Displays, Unterfunktionen, erklärungsintensiven Teile."
272		Service	02.13	Internal	"MPF Servicestelle in Österreich, Akkuhersteller in Deutschland – kurze Wege."
273		Service	02.13	Internal	"Servicesoftware nicht nötig, da über das Display sämtliche Funktionen überprüft und diagnostiziert werden können. Darüber hinaus gibt es einen Tester, der dem Händler bei Bedarf zur Verfügung gestellt werden kann."
274		Service	02.13	Internal	"Servicesoftware ist stark betreuungsbedürftig, hoher zusätzlicher Aufwand, wenn der Antriebshersteller nicht den Support übernimmt."
275		Trail & Pure (25/40): Design	02.13	Internal	"Eigenständig"

276		Trail & Pure (25/40): Design	02.13	Internal	"Unverwechselbar / einzigartig"
277		Trail & Pure (25/40): Design	02.13	Internal	"Hoher Differenzierungs- und Wiedererkennungsfaktor"
278		Trail & Pure (25/40): Technik	02.13	Internal	"State of the Art (Mittelmotorkonzept, Akkuleistung & Reichweite)"
279		Trail & Pure (25/40): Technik	02.13	Internal	"Höchste Effizienz (Skalierbare Modelle/ 25er / 40er Varianten) = Belegung der wichtigsten Produktgruppen Urban/Trekking & MTB"
280		Trail & Pure (25/40): Technik	02.13	Internal	"Sehr gutes Preis / Leistungsverhältnis (Ausstattung vs. Preis)"
281		Trail & Pure (25/40): Service	02.13	Internal	"Hoher Supportlevel"
282		Trail & Pure (25/40): Service	02.13	Internal	"Seitens Retail leistbar "
283		Trail & Pure (25/40): Sales	02.13	Internal	"Hochattraktives Pricing für alle Vertriebsstufen"
284		Trail & Pure (25/40): Sales	02.13	Internal	"Fachhandelsorientierung (höchste Beratungsqualität = 69% Kaufanteil beim Endverwender)"
285		Trail & Pure (25/40): Sales	02.13	Internal	"Konzentration auf die Absatzstärksten produktrelevanten Märkte in Europa mit effizienten Vertriebsnetz"
286		Trail & Pure (25/40): Marketing	02.13	Internal	"Höchste Markenidentifikation / Corporate Design"
287		Trail & Pure (25/40): Marketing	02.13	Internal	"Made in Germany"
288		Trail & Pure (25/40): Marketing	02.13	Internal	"Permanente Bearbeitung des Marktes im Vertrieb und Medien, inkl. POS Ausstattungen"
289		Trail	02.13	Internal	"Made in Germany"
290		Trail	02.13	Internal	"Fullsuspension"
291		Trail	02.13	Internal	"Hoher Wiedererkennungseffekt (Potential zum Kultfaktor)"
292		Pure	02.13	Internal	"Made in Germany"
293		Pure	02.13	Internal	"Bestes Preis Leistungsverhältnis"
294		Pure	02.13	Internal	"Voll ausgestattet / voll alltagstauglich"
295		Conclusion	02.13	Internal	"Im Wettbewerbsvergleich erfüllen die Third Element Produkte alle wichtigen kaufrelevanten Merkmale"
296		Conclusion	02.13	Internal	"Preis Leistung "

297		Conclusion	02.13	Internal	"Antriebskonzept und Akkuleistung für alle relevanten Klassen (25Km/h und 40Km/h)"
298		Conclusion	02.13	Internal	"Made in Germany"
299		Conclusion	02.13	Internal	"Eigenständiges, unverwechselbares Design"
300		Conclusion	02.13	Internal	"Höchste Qualität"
301		Conclusion	02.13	Internal	"Bester Service"
302	Internal evaluation "Anforderungen Urban eBike 20120308"	Hardtail 25/45	03.12	Internal	"Wichtig: Hohe Spitzenlastunterstützung"
303		Hardtail 25/45	03.12	Internal	"Wichtig: Hohe Reichweite"
304		Hardtail 25/45	03.12	Internal	"Sehr wichtig: Hohe Anmutung"
305		Hardtail 25/45	03.12	Internal	"Sehr wichtig: Hohe Zuverlässigkeit"
306		Hardtail 25/45	03.12	Internal	"Sehr wichtig: Geringer Wartungsaufwand"
307		Hardtail 25/45	03.12	Internal	"Weniger wichtig: Hohe Bergsteifähigkeit"
308		Hardtail 25/45	03.12	Internal	"Weniger wichtig: Geringe Anschaffungskosten"
309		Hardtail 25/45	03.12	Internal	"Weniger wichtig: Hohe Fahrradähnlichkeit"
310		Hardtail 25/45	03.12	Internal	"Sehr wichtig: Einfache Benutzung"
311		Hardtail 25/45	03.12	Internal	"Wichtig: Leichte Laufeigenschaften"
312		Hardtail 25/45	03.12	Internal	"Wichtig: Hohe Unterstützung"
313	Sales feedback "Händlerfeedback Produkte März 2013"	Pure / Trail	03.13	Business	"Schutzkappen bei Motoraufhängung (Schrauben / Muttern) als Korrosions- bzw. Rostschutz"
314		Pure / Trail	03.13	Business	"Der Lack wird als zu empfindlich betrachtet, Bowdenzüge scheuern und könnten Lackschicht freilegen?"
315		Pure / Trail	03.13	Business	"Batteriegehäuse wird als zu „unrobust“ empfunden"
316		Pure / Trail	03.13	Business	"Testfahrt mit Trail40. Fand das Rad nicht stabil beim Kurvenfahren. Schweißnähte nicht hochwertig genug."
317		Pure / Trail	03.13	Business	"Schutzbleche zu instabil"
318		Pure / Trail	03.13	Business	"Schutzbleche zu nahe am Reifen"
319	Test drive evaluation "Pure 40 Fahrtest"	Pure 40: Drive	08.13	Consumer	"Motorunterstützung bei langsamer Fahrt recht schubweise à eine konstante Geschwindigkeit kann nicht gut gehalten werden (z.B. bei 20 km/h)"

320		Pure 40: Drive	08.13	Consumer	"Bei Anstiegen bricht Geschwindigkeit weit ein und kann nur durch kräftige Fahrerbeteiligung aufrechterhalten werden"
321		Pure 40: Drive	08.13	Consumer	"Nach etwa 30/22/20 km gefahrener Strecke unter Höchstunterstützung und aggressiver Fahrweise schaltete der Display Modus zum reinen Fahrradtacho Modus um und versagte jegliche Unterstützung trotz Batterierestfüllung (1/2 Balken); kein Einschalten der Fahrradbeleuchtung möglich"
322		Pure 40: Drive	08.13	Consumer	"Sich wiederholendes An- und Abschalten des Ladegeräts über längeren Zeitraum (> 30 min) bei besagter, folgender Aufladung"
323		Pure 40: Drive	08.13	Consumer	"Kein „sauberes" Abschalten bei „leerfahren" der Batterie, kurzzeitige Schubartige Unterstützung"
324		Pure 40: Drive	08.13	Consumer	"Fest installiertes Display (gesetzlich Vorgeschrieben?) ersetzt einen Tacho nur unzureichend, da Datenauswertung nur zur Zeit des Fahrens oder bei Aufenthalt beim Fahrradmöglich ist."
325		Pure 40: Drive	08.13	Consumer	"10 Untestützungsstufen erscheinen zunächst überflüssig, High, Medium und Low würden als Freizeitfahrer reichen, "
326		Pure 40: Drive	08.13	Consumer	"Für Pendler kann allerdings so die Unterstützung (10 Stufen) auf die Akkukapazität und Fahrtdistanz (bekannt) besser angepasst werden"
327		Pure 40: Accessories	08.13	Consumer	"Merkliches (lautes) Reiben des offenen Chaingliders"
328		Pure 40: Accessories	08.13	Consumer	"Merkliche Vibration des vorderen Schutzbleches, beim Überfahren von Unebenheiten Klappergeräusche"
329		Pure 40: Accessories	08.13	Consumer	"Merkliches Anstoßen (Akustik) des Nummernschildes mit Halter (?!) bei größeren Unebenheiten"
330		Pure 40: Accessories	08.13	Consumer	"Erhebliches Reifengeräusch bei schneller Fahrt auf asphaltierter Strecke"
331		Pure 40: Accessories	08.13	Consumer	"Teilweise Vibration in höherer Frequenz (bei starkem Motoreinsatz ?) im vorderen Fahrzeugbereich (Lenker, Schutzblech?)"

332		Pure 40: Accessories	08.13	Consumer	"Merklicher Geschwindigkeitsverlust beim Schalten am Berg durch Kraftflussauskopplung, man kann eigentlich gleich 2 Gänge im Berg runterschalten sollte aber lieber vorausschauend fahren oder muss kräftig treten (Wiegetritt)"
333		Pure 40: Accessories	08.13	Consumer	"Bei Fahrt ohne Motorunterstützung sind Reisegeschwindigkeiten von über 20 km sehr sportlich, Anstiege kleine Herausforderungen"
334		Pure 40: Accessories	08.13	Consumer	"Zu leise Klingel um sich im Straßenverkehr Gehör zu verschaffen "
335	Test drive evaluation "eSpire Testsieger"	eSpire KBA 45	07.10	Business	(+) "Starke Unterstützung in allen Fahrsituationen"
336		eSpire KBA 45	07.10	Business	(+) "Hohe Reichweite im Tourengelände und im Stadtverkehr"
337		eSpire KBA 45	07.10	Business	(+) "Hohe Zuladung"
338		eSpire KBA 45	07.10	Business	(+) "14-Gang Nabenschaltung"
339		eSpire KBA 45	07.10	Business	(0) "Versicherungspflichtig"
340		eSpire KBA 45	07.10	Business	(–) "Hohes Gewicht"
341		eSpire KBA 45	07.10	Business	(–) "Motorgeräusch deutlich hörbar"
342		eSpire KBA 45	07.10	Business	(–) "Hoher Preis"
343		eSpire KBA 45	07.10	Business	(–) "Schwer fahrbar ohne Motor"
344	Test drive evaluation "E-Spire Testweekend Gardasee"	eSpire KBA 45	04.11	Consumer	(+) "Gasannahme auch im Stillstand"
345		eSpire KBA 45	04.11	Consumer	(+) "Federgabel ist Top (nach Einstellung)"
346		eSpire KBA 45	04.11	Consumer	(+) "Fahrstabilität"
347		eSpire KBA 45	04.11	Consumer	(+) "Motorunterstützung"
348		eSpire KBA 45	04.11	Consumer	(+) "Motorpfeifen"
349		eSpire KBA 45	04.11	Consumer	(+) "NuVinci Nabe"
350		eSpire KBA 45	04.11	Consumer	(+) "Griffige Pedale"
351		eSpire KBA 45	04.11	Consumer	(+) "Schmerzfreier Sattel"
352		eSpire KBA 45	04.11	Consumer	(+) "Aha Effekt"
353		eSpire KBA 45	04.11	Consumer	(+) "Am Berg erste Wahl (so lange der Akku hält"
354		eSpire KBA 45	04.11	Consumer	(-) "Restreichweite"
355		eSpire KBA 45	04.11	Consumer	(-) "Personal Trainer (Kalorien)"
356		eSpire KBA 45	04.11	Consumer	(-) "Höhenmesser"
357		eSpire KBA 45	04.11	Consumer	(-) "Fahrstufen besser in „max Range“, „eco“, „PERFORMANCE“ "
358		eSpire KBA 45	04.11	Consumer	(-) "Evtl. GPS"
359		eSpire KBA 45	04.11	Consumer	(-) "Halterung für Kamera (Hero)"
360		eSpire KBA 45	04.11	Consumer	(-) "Hinterradführung verwindet

					sich"
361		eSpire KBA 45	04.11	Consumer	(-) "30% mehr Reichweite wünschenswert"
362		eSpire KBA 45	04.11	Consumer	(-) "Gasgriff mit weicherem Gummi"
363		eSpire KBA 45	04.11	Consumer	(-) "GPS Befestigung"
364		eSpire KBA 45	04.11	Consumer	(-) "Freiraum im Rahmen besser Nutzbar"
365		eSpire KBA 45	04.11	Consumer	(-) "Keine Beleuchtung am Fzg. Stecklösung"
366		eSpire KBA 45	04.11	Consumer	(-) "Zweitakku sinnvoll"
367		eSpire KBA 45	04.11	Consumer	(-) "Nummerntafelhalter nicht vorhanden"
368		eSpire KBA 45	04.11	Consumer	(-) "Viele Klappergeräusche, schlechter Qualitätseindruck bei Passanten"
369		eSpire KBA 45	04.11	Consumer	(-) "Design Seitenständer"
370		eSpire KBA 45	04.11	Consumer	(-) "Aluschutz sollte durchgängig sein"
371		eSpire KBA 45	04.11	Consumer	(-) "Schrauben haben Überstand"
372		eSpire KBA 45	04.11	Consumer	(0) "Drei Fahrstufen ausreichend"
373		eSpire KBA 45	04.11	Consumer	(0) "Instrument auch ohne E-Antrieb (zweistufiger Betrieb, vgl. Fzge mit Zündung)"
374		eSpire KBA 45	04.11	Consumer	(0) "Akku Ladeanzeige auf Handy"
375		eSpire KBA 45	04.11	Consumer	(-) "Zu viele frei verlaufende Leitungen"
376		eSpire KBA 45	04.11	Consumer	(-) "Kein durchgängiger Kettenschutz"
377	Physical folder "Marketing Strategie": External analysis "E-Bike Händlerbefragung Deutschland"	E-scooters in general	06.11	Business	(0) "Kaum learnings zu E-Scooter"
378		Pedelecs in general	06.11	Business	(+) "Starkes Wachstum bei Pedelecs"
379		Fast pedelecs in general	06.11	Business	(-) "Wachstum stagniert bzw. max. leichter Anstieg bei Fast-Pedelecs"
380		Fast pedelecs in general	06.11	Business	(0) "Entwicklung ist abhängig von restlicher Rahmensetzung, momentan unklar"
381		E-Bikes in general	06.11	Business	(+) "Fahrunterstützung bei Steigungen, Mithalten können, für gehandicappte Personen"
382		E-Bikes in general	06.11	Business	(+) "Weniger Ermüdung, mehr Spaß"
383		E-Bikes in general	06.11	Business	(+) "Längere Touren"
384		E-Bikes in general	06.11	Business	(+) "Wellness/ Fitness"
385		E-Bikes in general	06.11	Business	(+) "Alternative fürs Pendeln"

386		E-Bikes in general	06.11	Business	(-) "Preis"
387		E-Bikes in general	06.11	Business	(-) "Gewicht"
388		E-Bikes in general	06.11	Business	(-) "Angst vor schneller Technikentwicklung"
389		E-Bikes in general	06.11	Business	(-) "Bisheriges Image: Reha-Bike"
390		Pedelecs in general	06.11	Business	(0) "Preisobergrenze Pedelecs: 3000 €"
391		Fast pedelecs in general	06.11	Business	(0) "Preisobergrenze Fast-Pedelecs: 3000-7000€"
392		Pedelecs in general	06.11	Business	(+) "Größere Nähe zum Fahrrad: Wiedereinstieg, Bewegung, Spaß, Unterstützung im Alltag, Mobilität, Mithalten können in der Gruppe"
393		Pedelecs in general	06.11	Business	(+) "Pendler"
394		Pedelecs in general	06.11	Business	(+) "Keine rechtlichen Vorgaben"
395		Fast pedelecs in general	06.11	Business	(+) "Schnelles Fahren, Dynamik"
396		Fast pedelecs in general	06.11	Business	(+) "Spaß"
397		Fast pedelecs in general	06.11	Business	(+) "Pendler, Streckenmacher"
398		Pedelecs in general	06.11	Business	(-) "Teils zu langsam"
399		Pedelecs in general	06.11	Business	(-) "Zu wenig Informationen"
400		Pedelecs in general	06.11	Business	(-) "Design veraltet"
401		Pedelecs in general	06.11	Business	(-) "Kein Rücktritt"
402		Fast pedelecs in general	06.11	Business	(-) "Unklarer gesetzlicher Rahmen"
403		Fast pedelecs in general	06.11	Business	(-) "Helmpflicht"
404		Fast pedelecs in general	06.11	Business	(-) "Versicherung"
405		Fast pedelecs in general	06.11	Business	(-) "Hat kaum noch Fahrrad-Flair"
406		Fast pedelecs in general	06.11	Business	(-) "Zu schwer"
407		E-Bikes in general	06.11	Business	"Batteriekapazität top wichtig (Platz 1)"

408		E-Bikes in general	06.11	Business	"Marke sehr wichtig (Platz 2)"
409		E-Bikes in general	06.11	Business	"Antrieb wichtig (Platz 3)"
410		E-Bikes in general	06.11	Business	"Lebensdauer Batterie wichtig (Platz 3)"
411		Pedelecs and fast pedelecs in general	06.11	Business	"Probefahrt Kaufargument"
412		Pedelecs and fast pedelecs in general	06.11	Business	"Reichweite Kaufargument"
413		Pedelecs and fast pedelecs in general	06.11	Business	"Serviceleistungen Kaufargument"
414		Pedelecs in general	06.11	Business	"Gewährleistung Akku Kaufargument"
415		Pedelecs in general	06.11	Business	"Betriebssicherheit Kaufargument"
416		Fast pedelecs in general	06.11	Business	"Preisvergleich Auto beim Pendeln Kaufargument"
417		Fast pedelecs in general	06.11	Business	"Leasingmöglichkeiten Kaufargument"
418		E-Bikes in general	06.11	Business	"Akkutechnologie: Mehr Zuverlässigkeit und mehr Leistung"
419		E-Bikes in general	06.11	Business	"Intelligente Ladetechnik, keine Ladefehler"
420		E-Bikes in general	06.11	Business	"Kleines Reiseladegerät"
421		E-Bikes in general	06.11	Business	"Schnelladefähigkeit"
422		E-Bikes in general	06.11	Business	"Ein- und ausgesteckt ladefähig"
423		E-Bikes in general	06.11	Business	"Display Mittelding zwischen zu wenig und zu viel Elektronik"
424		E-Bikes in general	06.11	Business	"Fahrrad auch ohne Antrieb gut fahrbar"
425		E-Bikes in general	06.11	Business	"Umstellmöglichkeit von hoher Endgeschwindigkeit zu viel Drehmoment und umgekehrt"
426		E-Bikes in general	06.11	Business	"Anzeige der Restreichweite basierend auf Fahrverhalten"
427		E-Bikes in general	06.11	Business	"Attraktive Formen um Jüngere anzusprechen"
428		E-Bikes in general	06.11	Business	"Je cooler desto besser, vor allem 25 km/h Pedelecs müssen wie Fahrräder aussehen"

429		E-Bikes in general	06.11	Business	"Tiefeinstieg ist erwünscht"
430		E-Bikes in general	06.11	Business	"Weniger Gewicht bei gleichzeitig mehr Reichweite"
431		E-Bikes in general	06.11	Business	"Mehr Zubehör, auf Details konzentrieren (Komponenten)"
432		E-Bikes in general	06.11	Business	"Preis weiter nach unten bringen"
433		E-Bikes in general	06.11	Business	"Weniger Gewicht "
434		E-Bikes in general	06.11	Business	"Gute Qualität in der Gesamtverarbeitung"
435		E-Spire Comp	09.11	Internal	(-) "Gewicht zu hoch"
436		E-Spire Comp	09.11	Internal	(-) "Look zu wuchtig"
437		E-Spire Comp	09.11	Internal	(-) "Zu nah am Motorrad"
438		E-Spire Comp	09.11	Internal	(-) "Preis an der Obergrenze für Pedelecs"
439		E-Spire Comp	09.11	Internal	(-) "Marktsegment "FUN" mit Abstand das Kleinste"
440		E-Spire Comp	09.11	Internal	(+) "Marktsegment "FUN" noch nicht belegt - Blue-Ocean Strategie"

APPENDIX 2. Design matrix prior to decoupling

DPs

FRs			1						2													3			4			5			6					7		8	
				1	2	3	4	5		1	2				3	4	5	6	7				1	2		1	2		1	2		1	2	3	4		1		1
												1	2	3						1	2																		
1			x																																				
	1			x																																			
	2				x																																		
	3					x																																	
	4						x																																
	5							x																															
2			x						x													x														x			
	1			x						x																													
	2										x																												
		1										x																											
		2										x	x																										
		3												x																									
	3			x						x		x		x	x			x	x					x															
	4															x																				x			
	5			x													x																						
	6															x		x																					
	7										x					x		x	x																				
		1														x		x		x																			
		2									x					x		x			x																		
3			x																			x																	
	1			x		x																	x																
	3																							x															
4									x																x														
	1									x																x													
	2									x																	x												
5																												x											
	1																						x						x										
	2																													x									
6			x																												x							x	
	1			x		x																									x	x							x
	2																														x	x	x						
	3																														x	x	x	x					x
	4																																		x				
7			x						x																											x			
	1			x		x				x																											x		
8			x																												x							x	
	1					x																										x		x					x

Figure 16. Design matrix prior to decoupling.